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DIGITAL TRANSMISSION EVALUATION PROJECT
MW-518 (QPSK) TEST
INTERIM REPORT

BY

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DECEMBER 1974

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Collins Radio MW-518 (QPSK) digital radio was tested in back-to-back con- figuration for determination of transfer parameters to isolate propagation effects in link testing and the development of standard test techniques. The radio has a maximum propagation rate of 19.804 Mb/s (288 voice channels) at 8.11 GHz and other rates selection of 12.553 Mb/s, 6.276 Mb/s, and 1.544 Mb/s. BER vs RSL characteristics are displayed and analyzed as the primary mode of equipment evaluation. Carrier to interference data, T-1 line tests and theoret- ical predictions are compared. Frequency stability, quantizing (Continued)		

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distortion, crosstalk, orderwire, signal to noise ratio, and data rate variations are measured and presented. Power Spectra are displayed and compared to FCC requirements.

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1. BACKGROUND.

1.1 Introduction.

1.1.1 This document reports the results of tests performed on engineering models of the Collins MW-518 (QPSK) radio sets in a back-to-back configuration. This equipment was tested as part of the US Army Communications Command (USACC) Digital Transmission Evaluation Project (DTEP) during the period from 24 June 1974 to 9 December 1974.

1.1.2 By Department of the Army tasking the USACC issued Communications-Electronics Mission Order B74FUS136 in October 1973 to start the DTEP. This project contributes to the Army's efforts in the area of commercial developments under DCA Circular 330-195-2.

1.1.3 The US Army Communications Systems Agency (USACSA), Fort Monmouth, NJ is responsible for managing the DTEP. Actual conduct of the tests was delegated to the US Army Electronic Proving Grounds (USAEPG) Fort Huachuca, Arizona under the engineering guidance and supervision of the US Army Communications-Electronics Engineering Installation Agency (USACEEIA), Fort Huachuca, Arizona.

1.2 Approach to the Task.

1.2.1 The tasking documents for the DTEP establish several broad functions of equipment testing to be investigated and determined:

- a. Interface parameters between items of equipment.
- b. Transfer parameters within the system.
- c. Propagation path influences on transfer parameters.
- d. Test techniques and methodology.

1.2.2 To facilitate testing and limit variables, evaluations were scheduled in two phases. The first phase, known as the back-to-back test, consisted of a series of tests with the equipment in a common location connected by waveguide and cabling. This configuration allowed having accurate baseline parameters, proper test techniques, and performance tests which could not be conducted on an active link with the desired degree of confidence.

1.2.3 The second phase of evaluations will be performed on an active link from Fort Huachuca to a repeater site located in Texas Canyon near Benson, AZ, a distance of approximately 32 miles (51 kilometers).

1.3 Summary of Results and Conclusions.

1.3.1 Engineering models of the MW-518 (QPSK) were subjected to extensive tests which produced data on many aspects of Quadrature Phase Shift Keyed (QPSK) System performance. One result of the tests was the determination that a signal-to-noise ratio of greater than 13 dB is required for carrier recovery in the detector, and that the E_b/N_0 ratio is a valid measurement to compare the equipment with actual and theoretical performance. Analysis of bit error rate (BER) performance in systems with differing amounts of transmitter filtering is provided with observations on the system degradation.

1.3.2 Transmitted spectrums are analyzed with respect to the requirements of FCC Docket 19311, which establishes limits to out-of-band emissions, with the finding that only one spectrum in six is fully compliant.

1.3.3 Tests performed in a systems configuration employing the CY-104 PCM channel bank and the VICOM T1-4000 8-port time division multiplexer (TDM) which concluded that the TDM contributes no degradation to the bit streams from the primary multiplexers, and that the voice level tests of quantizing distortion and channel crosstalk are strictly affected by characteristics in the PCM channel bank and are not degraded in transmission through an RF system.

2. GENERAL.

2.1 Description of Equipment.

2.1.1 The MW-518 (QPSK) tested in the DTEP is an engineering model of a modification package for the commercial MW-518 FDM-FM radio set manufactured by Collins Radio Company. The basic objective of the modification package was to enable transmission of a digital bit stream employing QPSK modulation, while retaining the capability of 600 channel FDM operation. While this goal was accomplished, the performance of the equipment in the QPSK mode is not suitable for an operating system because of excessive out-of-band emissions necessitated by the wide bandwidth of the RF filters to allow 600 channel FDM operation.

2.1.2 Figure 1 is a block diagram of the receiver-transmitters furnished. The components in the dashed areas are modules which were added to enable QPSK operation. The basic microwave transmitter was unchanged up to the waveguide RF filter. The modulation

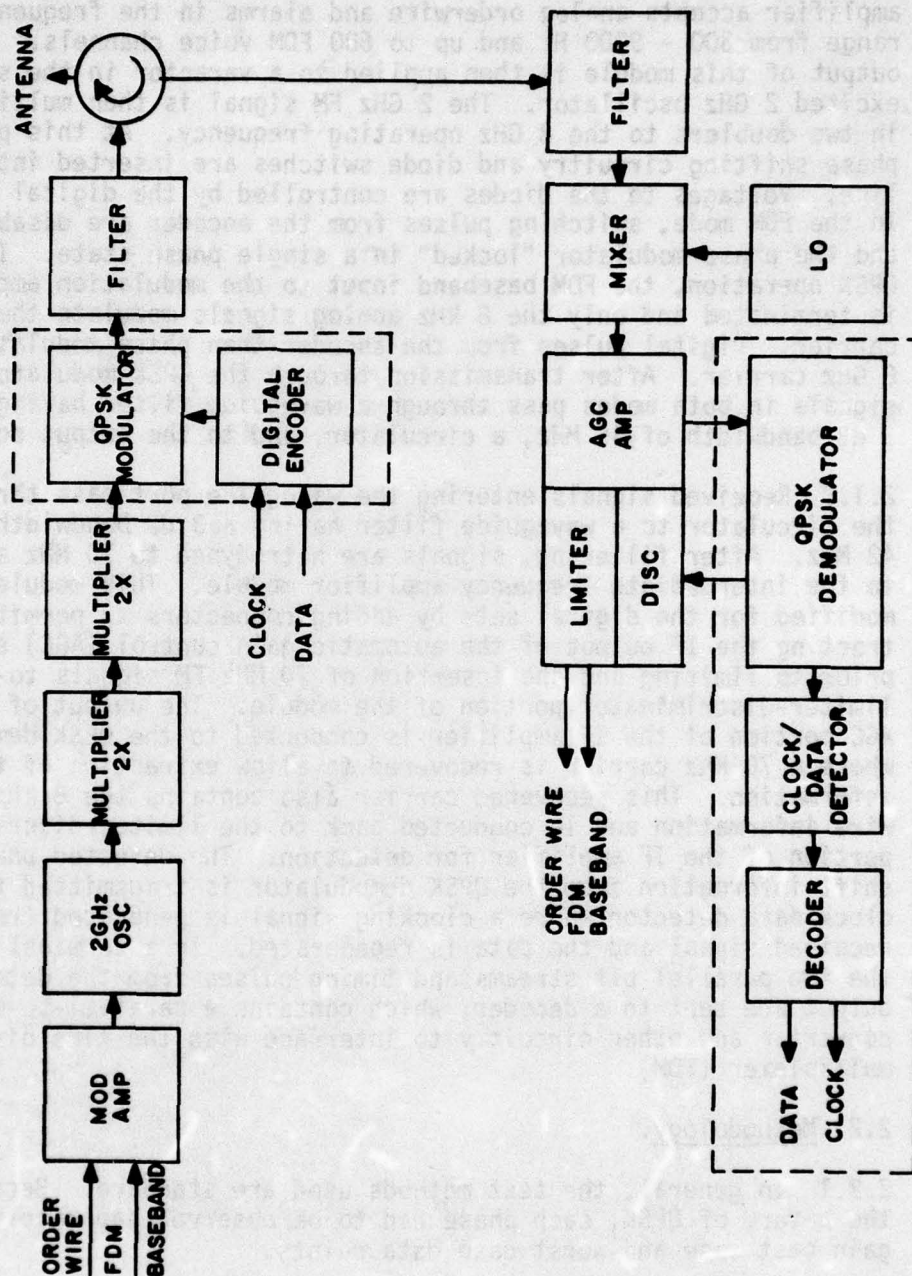


Figure 1 MW-518 (QPSK) System

amplifier accepts analog orderwire and alarms in the frequency range from 300 - 8000 Hz and up to 600 FDM voice channels. The output of this module is then applied to a varactor in the self-excited 2 GHz oscillator. The 2 GHz FM signal is then multiplied in two doublers to the 8 GHz operating frequency. At this point, phase shifting circuitry and diode switches are inserted into the line. Voltages to the diodes are controlled by the digital encoder. In the FDM mode, switching pulses from the encoder are disabled and the phase modulator "locked" in a single phase state. In QPSK operation, the FDM baseband input to the modulation amplifier is terminated and only the 8 kHz analog signals modulate the RF carrier. Digital pulses from the encoder then phase modulate the 8 GHz carrier. After transmission through the QPSK modulator, signals in both modes pass through a waveguide filter having a 3 dB bandwidth of 45 MHz, a circulator, and to the output port.

2.1.3 Received signals entering the waveguide port pass through the circulator to a waveguide filter having a 3 dB bandwidth of 42 MHz. After filtering, signals are heterodyned to 70 MHz and passed to the intermediate frequency amplifier module. This module was modified for the digital sets by adding connectors to permit extracting the IF output of the automatic gain control (AGC) section prior to limiting and the insertion of 70 MHz FM signals to the limiter-discriminator portion of the module. The output of the AGC portion of the IF amplifier is conducted to the QPSK demodulator where a 70 MHz carrier is recovered to allow extraction of the phase information. This recovered carrier also contains the 8 kHz orderwire information and is conducted back to the limiter-discriminator portion of the IF amplifier for detection. The detected phase shift information from the QPSK demodulator is transmitted to the clock/data detector where a clocking signal is generated from the received signal and the data is regenerated. In a terminal location, the two parallel bit streams and timing pulses from the detector output are sent to a decoder, which contains a parallel-to-serial converter and other circuitry to interface with the time division multiplexer (TDM).

2.2 Methodology.

2.2.1 In general, the test methods used are standard. Because of the nature of QPSK, each phase had to be observed separately to gain best case and worst case data points.

2.2.2 The radio measurement of signal levels were made at the input to the wave guide and not at the input to the mixer, which is normal practice.

2.3 Limitations. There were no unusual limitations encountered in this study. Limits on the data generally are established by limits of the test equipment which was constantly monitored for correct calibration.

3. DETAILS OF TESTS.

3.1 BER vs RSL.

3.1.1 The purpose of this test was to gather data for plotting bit error rate against various received signal levels. These curves yield important information for use in evaluating digital equipment. Effects of thermal noise, intersymbol interference, and bandwidth are readily apparent and easily analyzed. Overall receiver performance can be analyzed by comparing the data from this test and theoretical predictions.

3.1.2 Procedure.

3.1.2.1 Employing the equipment configuration in Figure 2, pseudo-random data was generated at the desired rate and transmitted over the simulated RF link. Path attenuation was introduced with attenuators in the waveguide transmission line. Measurements of errors in the received data were made at selected received signal levels (RSL).

3.1.2.2 As various components were changed, the bit error rate (BER) was remeasured to determine the effects of those changes.

3.1.3 Results and Analysis.

3.1.3.1 The first series of BER versus RSL plots concentrated on the 12.5526 Mb/s rate. The method of carrier recovery employed with this set (multiplying the received signal by four to remove phase transitions) produced a family of four distinct curves depending on which phase state was selected for data detection. Minor distortions in the eye patterns of the "I" and "Q" data channels as displayed on an oscilloscope were keyed to the operation in different phase lock conditions and arbitrarily numbered. Figure 3 displays the initial performance of the equipment. Of special note is that the receiver assumed an "out-of-lock" condition approximately 1 dB higher in RSL when operating in the arbitrary Phase I state. The Phase 3 curve appears truncated at a -79 dBm RSL, however, this is due to the recording of zero errors in that phase state at a -78 dBm RSL. The total spread between the curves is approximately 0.6 dB.

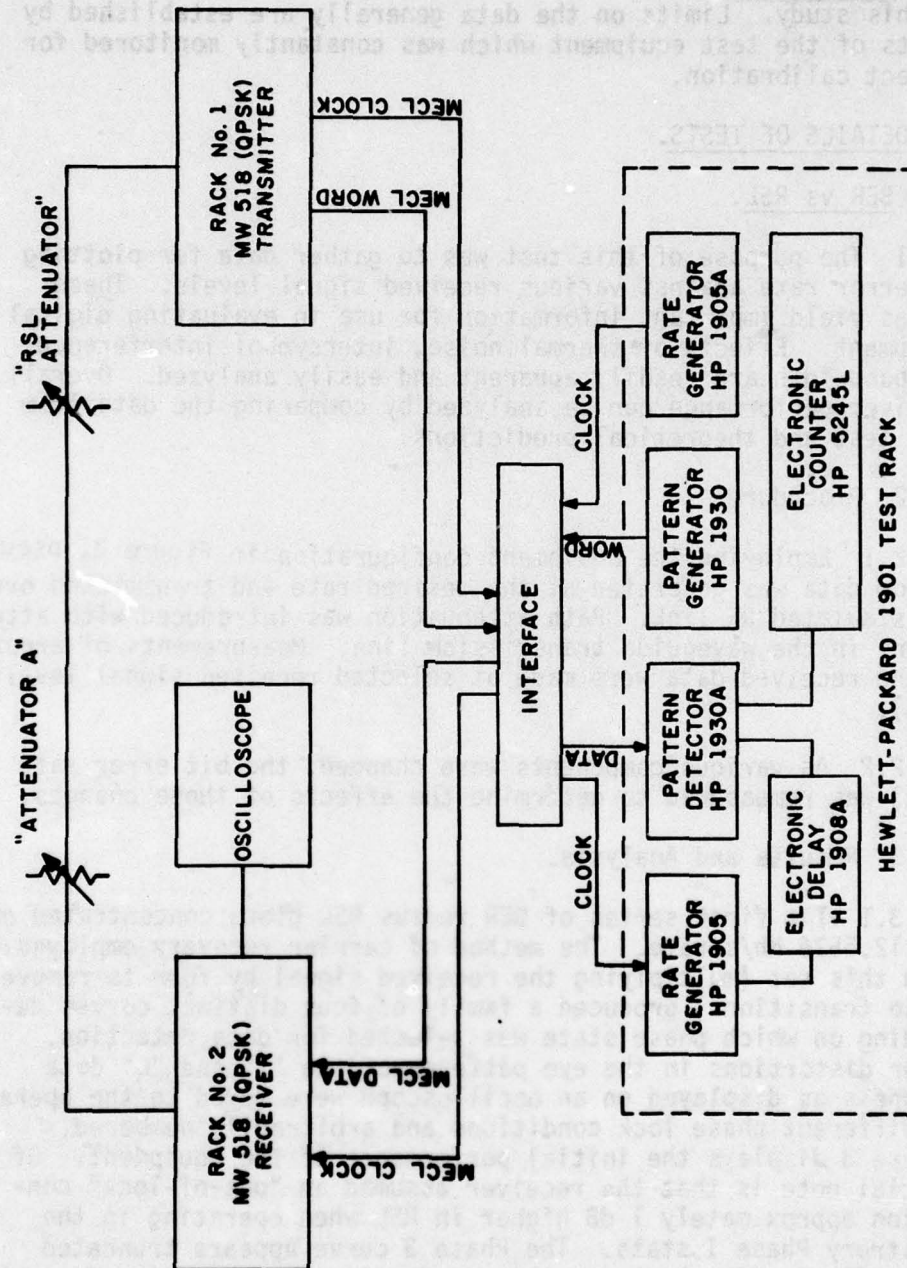


Figure 2 BER vs RSL Test Configuration

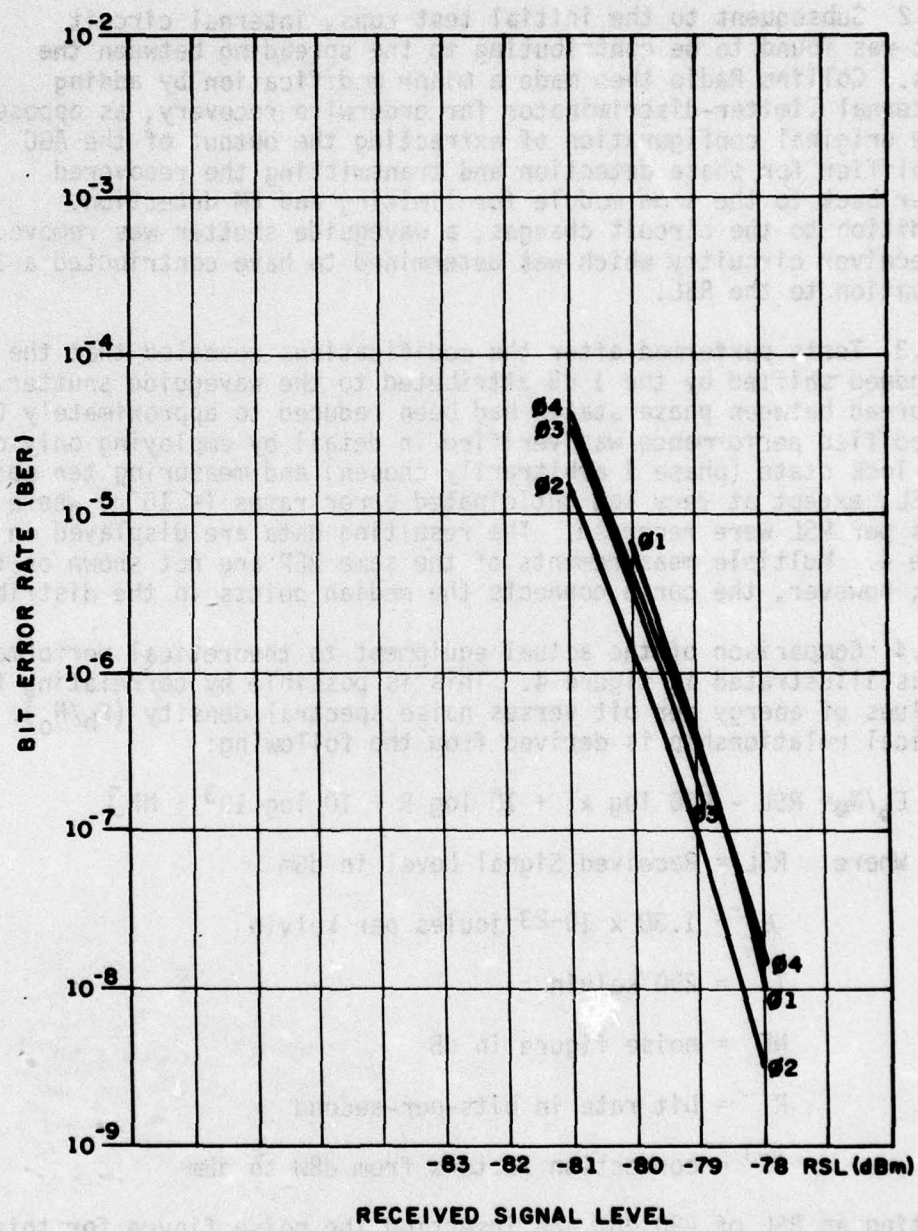


Figure 3 BER vs RSL (Four Phase States)

3.1.3.2 Subsequent to the initial test runs, internal circuit layout was found to be contributing to the spreading between the curves. Collins Radio then made a minor modification by adding an external limiter-discriminator for orderwire recovery, as opposed to the original configuration of extracting the output of the AGC IF amplifier for phase detection and transmitting the recovered carrier back to the same module for limiting and FM detection. In addition to the circuit changes, a waveguide shutter was removed from the receiver circuitry which was determined to have contributed a 1 dB attenuation to the RSL.

3.1.3.3 Tests performed after the modifications revealed that the curves had indeed shifted by the 1 dB attributed to the waveguide shutter, and the spread between phase states had been reduced to approximately 0.3 dB. The modified performance was verified in detail by employing only one phase lock state (phase 1 arbitrarily chosen) and measuring ten points per RSL, except at very low anticipated error rates ($<10^{-9}$) where five points per RSL were recorded. The resulting data are displayed in figure 4. Multiple measurements of the same BER are not shown on the curve; however, the curve connects the median points in the distributions.

3.1.3.4 Comparison of the actual equipment to theoretical performance also is illustrated in figure 4. This is possible by correlating the RSL to values of energy per bit versus noise spectral density (E_b/N_0). The numerical relationship is derived from the following:

$$E_b/N_0 = \text{RSL} - [10 \log kT + 10 \log R + 10 \log 10^3 + \text{NF}]$$

Where: RSL = Received Signal Level in dBm

k = 1.38×10^{-23} joules per kelvin

T = 290 kelvin

NF = noise figure in dB

R = bit rate in bits-per-second

10^3 = correction factors from dBW to dBm

Selecting an RSL of -80 dBm and inserting the noise figure for this receiver of 8.5 dB, the formula yields:

$$E_b/N_0 = -80 - [-174 + 71 + 8.5]$$

$$E_b/N_0 = 14.5 \text{ for an RSL of } -80 \text{ dBm.}$$

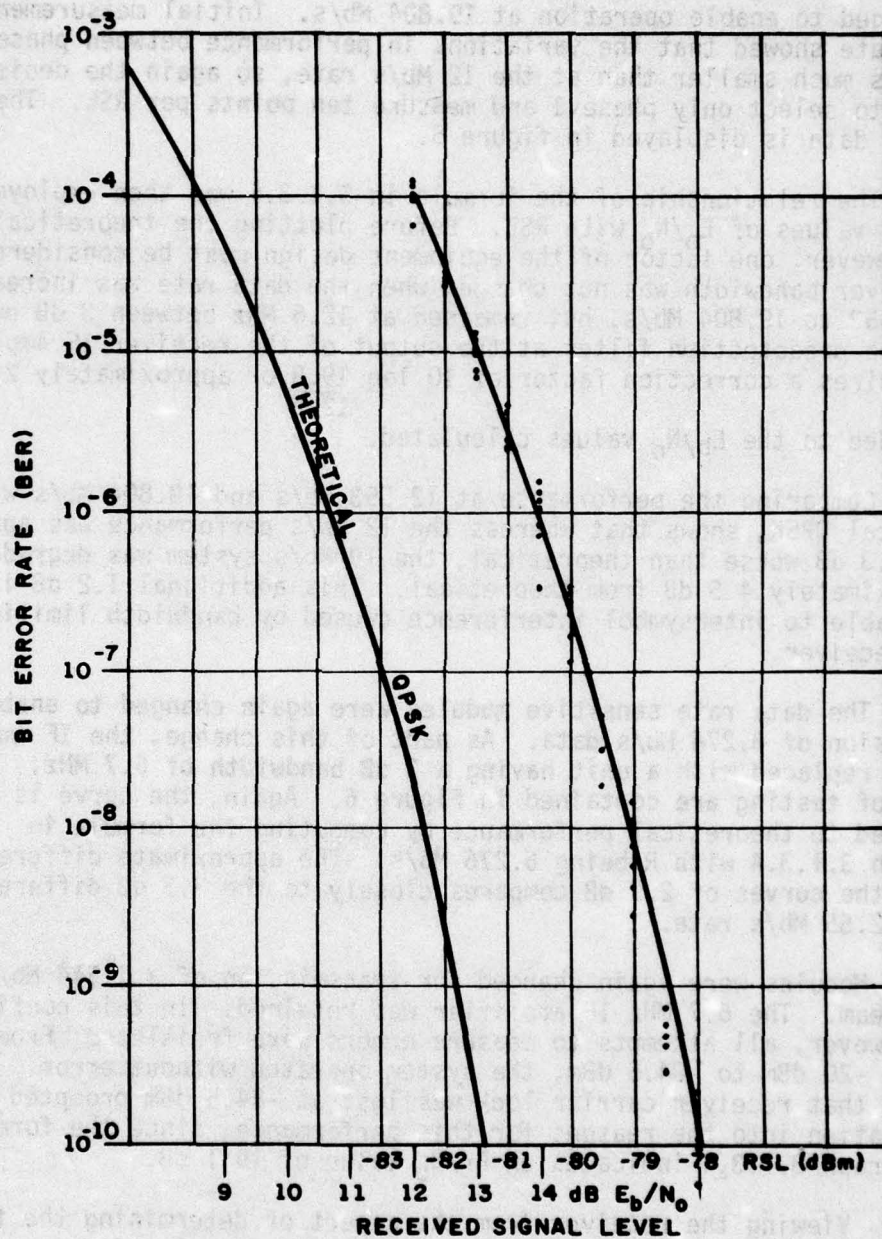


Figure 4 BER vs RSL (R = 12.6 Mb/s)

3.1.3.5 Following the tests at 12.553 Mb/s, bit rate sensitive modules were changed to enable operation at 19.804 Mb/s. Initial measurements at this rate showed that the variations in performance between phase states was much smaller than at the 12 Mb/s rate, so again the decision was made to select only phase 1 and measure ten points per RSL. The resultant data is displayed in figure 5.

3.1.3.6 The relationship of the formula in 3.1.3.4 was then employed to correlate values of E_b/N_0 with RSL. Before plotting the theoretical curve, however, one factor of the equipment design must be considered. The receiver bandwidth was not changed when the data rate was increased from 12.553 to 19.804 Mb/s, but remained at 12.6 MHz between 3 dB points due to the predetection filter at the output of the receiver IF amplifier. This requires a correction factor of $10 \log \frac{19.8}{12.6}$ or approximately 2 dB

to be added to the E_b/N_0 values calculated.

3.1.3.7 Comparing the performance at 12.553 Mb/s and 19.804 Mb/s with theoretical QPSK, shows that whereas the 12 Mb/s performance was approximately 3.3 dB worse than theoretical, the 19 Mb/s system was degraded to approximately 4.5 dB from theoretical. This additional 1.2 dB is attributable to intersymbol interference caused by bandwidth limiting in the receiver.

3.1.3.8 The data rate sensitive modules were again changed to enable transmission of 6.276 Mb/s data. As part of this change, the IF amplifier was replaced with a unit having a 3 dB bandwidth of 6.7 MHz. The results of testing are contained in Figure 6. Again, the curve is contrasted to theoretical performance by computing the formula in paragraph 3.1.3.4 with R being 6.276 Mb/s. The approximate difference between the curves of 2.9 dB compares closely to the 3.3 dB difference at the 12.55 Mb/s rate.

3.1.3.9 Modules were again changed for transmission of a 1.544 Mb/s data stream. The 6.7 MHz IF amplifier was retained. In this configuration, however, all attempts to measure errors were fruitless. From RSL's of -20 dBm to -84.5 dBm, the system operated without error. The fact that receiver carrier lock was lost at -84.5 dBm prompted an investigation into the reasons for this performance, since the formula of paragraph 3.1.3.4 indicates an E_b/N_0 value of 19.1 dB.

3.1.3.10 Viewing the receiver from the aspect of determining the total signal-to-noise ratio at the detector input, the formula of paragraph 3.1.3.4 may be modified to yield:

$$S/N = RSL - (-174 + NF + 10 \log BW)$$

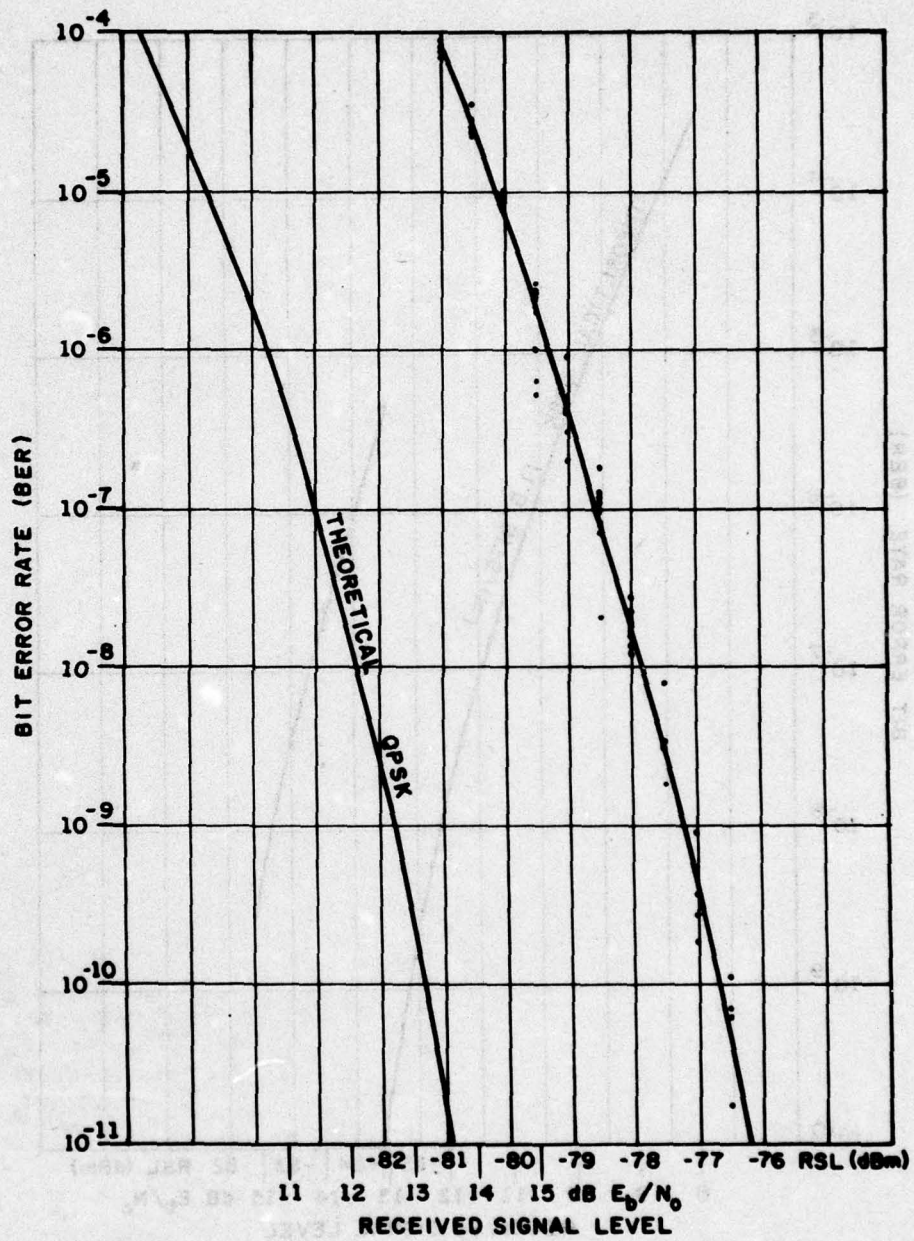


Figure 5 BER vs RSL (R = 19.8 Mb/s)

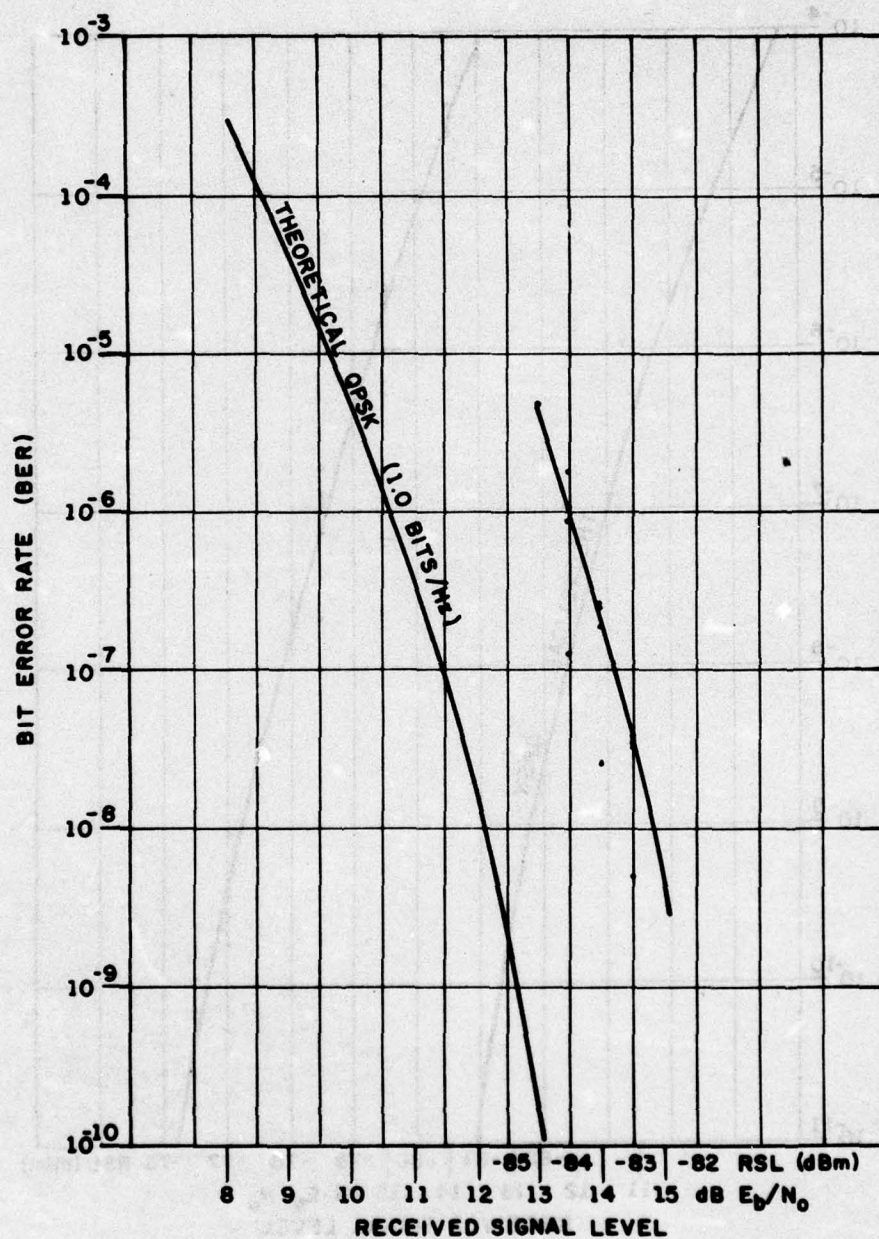


Figure 6 BER vs RSL (R = 6.3 Mb/s)

Where: RSL = received signal level in dBm

NF = noise figure in dB

BW = bandwidth of noise in receiver

$-174 = 10 \log kT$ in dBm/Hz

Working this through for the 1.544 Mb/s conditions yields:

$$S/N = -84.5 - (174 + 8.5 + 68.3)$$

$$= -84.5 - (-97.2)$$

$$S/N = 12.7 \text{ dB}$$

3.1.3.11 E_b/N_0 values at which carrier recovery lock was lost and the total signal-to-noise ratio at that point were then calculated for each of the bit rates with the following results:

Bit Rate (Mb/s)	Bandwidth (MHz)	Loss of Lock RSL (dBm)	E_b/N_0	S/N
19.804	12.6 (pre. det.)	-81.0	11.5	13.5
12.553	12.6 (pre. det.)	-82.5	12.0	12.5
6.276	6.7 (IF)	-84.5	13.0	12.7
1.544	6.7 (IF)	-84.5	19.1	12.7

From these results, while the values of E_b/N_0 are closely correlated with values of BER, the limiting factor in this system is the signal-to-noise ratio necessary to properly recover the carrier.

3.1.3.12 Late in the testing period, additional RF filters were delivered for the principal purpose of narrowing the transmitted spectrum to acceptable limits (see paragraph 3.3). Time constraints, however, did not permit extensive retesting with both 20 MHz and 14 MHz bandwidth RF filters. Only the 14 MHz RF filter was tested as being the most stringent of the filters available.

3.1.3.13 The purpose of the retest of BER versus RSL was to examine and measure the amount of degradation introduced by heavy filtering of the transmitted spectrum. The 14 MHz filter does not become the limiting factor in the system bandwidth since the predetection filter, employed in the receiver at the 12 and 19 Mb/s rates, and the 6.7 MHz IF amplifier, employed at the 6.2 and 1.5 Mb/s rates are narrower. Any degradation measured with these filters, then, should be due strictly to the effects of filtering in the transmitter.

3.1.3.15 Also, figure 7, shows the performance of the same system configuration with the 45 MHz filter from figure 4. Noteworthy in this display is that degradation is measured due to truncation of the transmitted spectrum and that the curve now diverges from the ideal slope as the RSL is increased. Apparently at higher RSL's where thermal noise becomes less significant, the distortions caused by filtering are the principal agents causing degradation. In high error rate regions, these distortions assume a secondary role in degrading the performance, and thermal noise predominates.

3.1.3.16 Data rate sensitive modules were again changed in order to test the effects of the 14 MHz RF filter with a 19.804 Mb/s data rate. Increased degradation was expected in this configuration due to the system approaching a 1.4 bits/Hz packing density with very heavy RF filtering. Figure 8 displays the results. Again, degradation was measured from the performance level with 45 MHz transmit filters. Also measured was a divergence from previous measurements as the RSL is increased. In this instance, the performance is degraded from previous levels by approximately 2.3 dB near a 10^{-4} BER, increasing to nearly 3 dB at a 10^{-9} BER.

3.1.3.17 From this series of tests, the performance of a QPSK system can be analyzed with respect to theoretical performance, and that filtering of the modulated spectrum introduces distortions into the system which, for other systems, can be estimated from the measured results contained herein.

3.2 Carrier-to-Interference (C/I) Ratio.

3.2.1 The purpose of this test was to gather data for plotting bit error rate against various received signal levels for five cases of added interference. These curves yield results necessary for the study of electromagnetic compatibility (EMC), and isolation between orthogonal planes of polarization as well as isolation among other systems in close geographic and spectral proximity.

3.2.2 Procedure. The test procedure included measuring data for C/I ratios of 12 dB, 15 dB, 18 dB, 21 dB and 24 dB, as well as the no-interference case. The equipment was connected as illustrated in figure 9. Calibration was conducted by setting the "RSL Attenuator" to zero and varying the "Interference Attenuator" to adjust the C/I level. A zero interference level was combined with a steady transmitter signal and the power was measured at the receiver mixer. Then the transmitter was disabled and the "Interference Attenuator" was adjusted for the appropriate power reading at the receiver for one C/I level. This completed the calibration and the test was conducted by varying only the "RSL Attenuator."

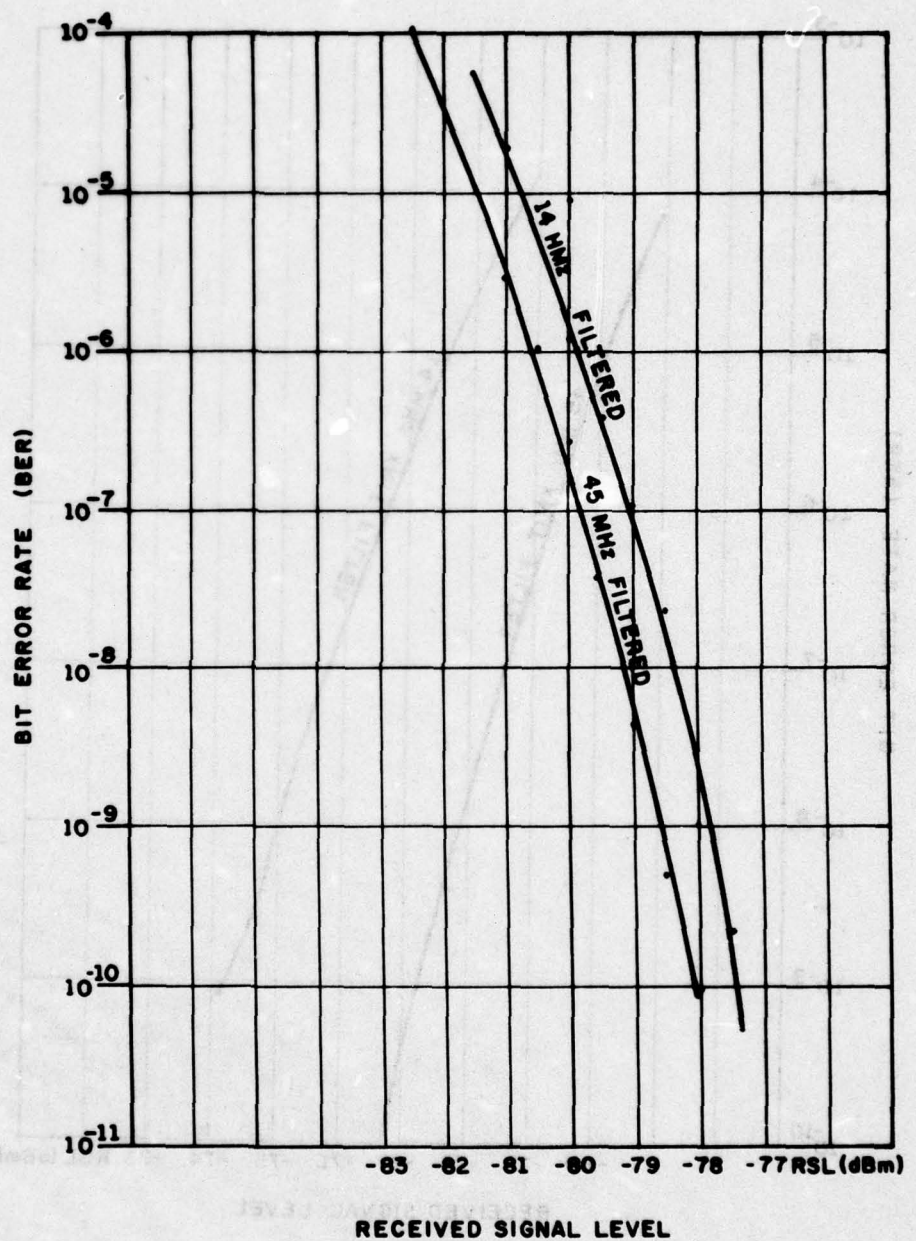


Figure 7 BER vs RSL (R = 12.6 Mb/s, B = 14 MHz)

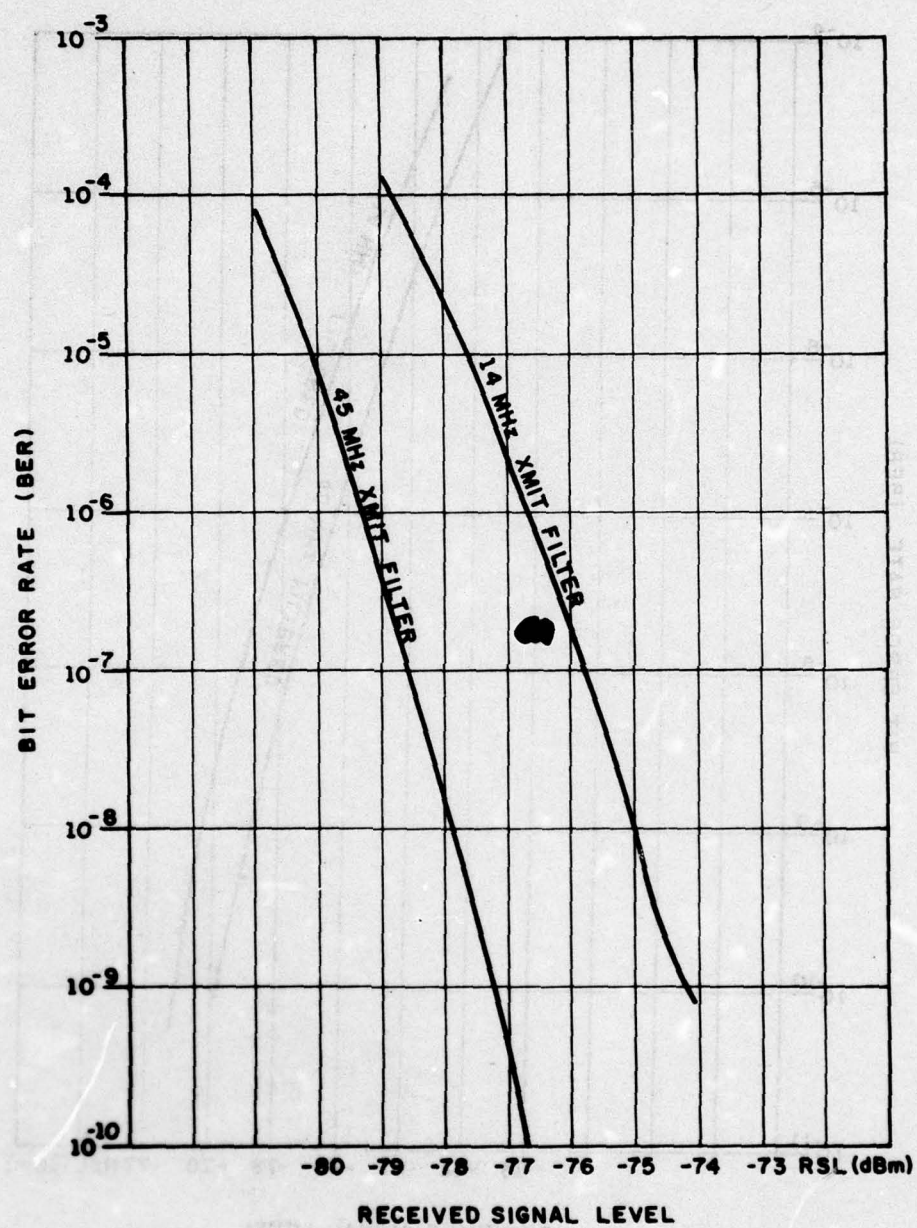


Figure 8 BER vs RSL (R = 19.8 Mb/s, B = 14 MHz)

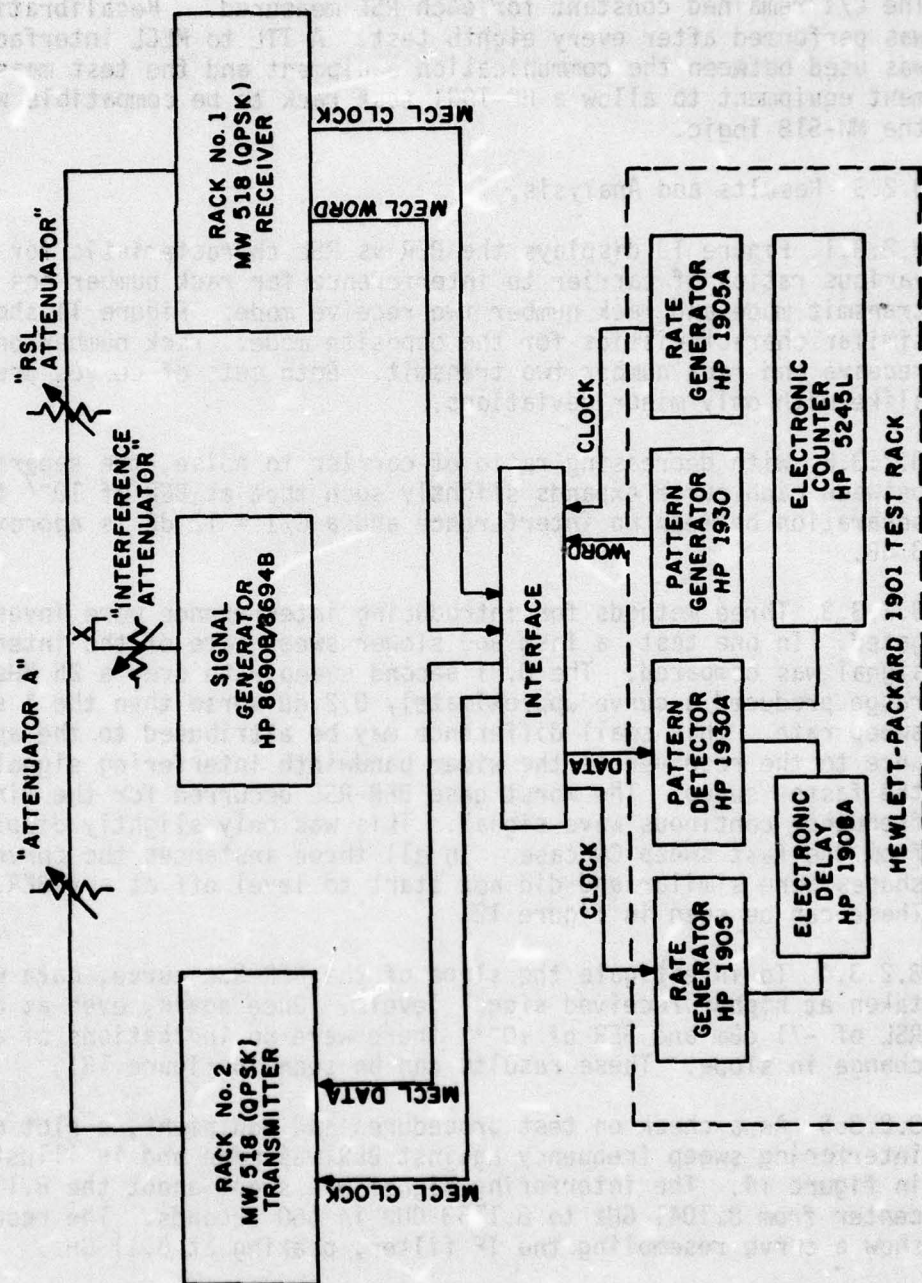


Figure 9 Carrier to Interference Test Configuration

The C/I remained constant for each RSL measured. Recalibration was performed after every eighth test. A TTL to MECL interface was used between the communication equipment and the test measurement equipment to allow a HP-1901 test rack to be compatible with the MW-518 logic.

3.2.3 Results and Analysis.

3.2.3.1 Figure 10 displays the BER vs RSL characteristic for various ratios of carrier to interference for rack number one transmit mode and rack number two receive mode. Figure 11 shows similar characteristics for the opposite mode: rack number one receive and rack number two transmit. Both sets of curves are alike with only minor deviations.

3.2.3.2 With decreasing ratio of carrier to noise, the separation between each curve expands slightly such that at BER of 10^{-7} the separation between no interference and a C/I = 12 dB is approximately 3 dB.

3.2.3.3 Three methods for introducing interference were investigated. In one test, a fast and slower sweep rate of the interfering signal was compared. The 0.01 second sweep rate over a 25 MHz range produced a curve approximately 0.2 dB worse than the 1 second sweep rate. This small difference may be attributed to the appearance to the receiver of the wider bandwidth interfering signal of the faster sweep. The worst case BER-RSL occurred for the single frequency continuous wave signal. This was only slightly displaced from the fast sweep CW case. In all three instances the curve shapes were similar and did not start to level off at any BER. These can be seen in figure 12.

3.2.3.4 To investigate the slope of the BER-RSL curve, data were taken at higher received signal levels. Once again, even at an RSL of -71 dBm and BER of 10^{-10} there were no indications of a change in slope. These results can be seen in figure 13.

3.2.3.5 As a check on test procedures and equipment, a plot of interfering sweep frequency against BER was made and is illustrated in figure 14. The interfering signal was swept about the 8.11 GHz center from 8.1041 GHz to 8.1153 GHz in 150 seconds. The results show a curve resembling the IF filter, peaking at 8.11 GHz.

3.2.3.6 The biggest question at this point of study is the nature of the detection circuit which allows increasing levels of interference with simple translation of the BER-RSL curve. That is, there was no leveling off at different C/I ratios for bit error rate. This indicates that the data recovery technique was not affected at all by the interference, only the carrier recovery stage degraded.

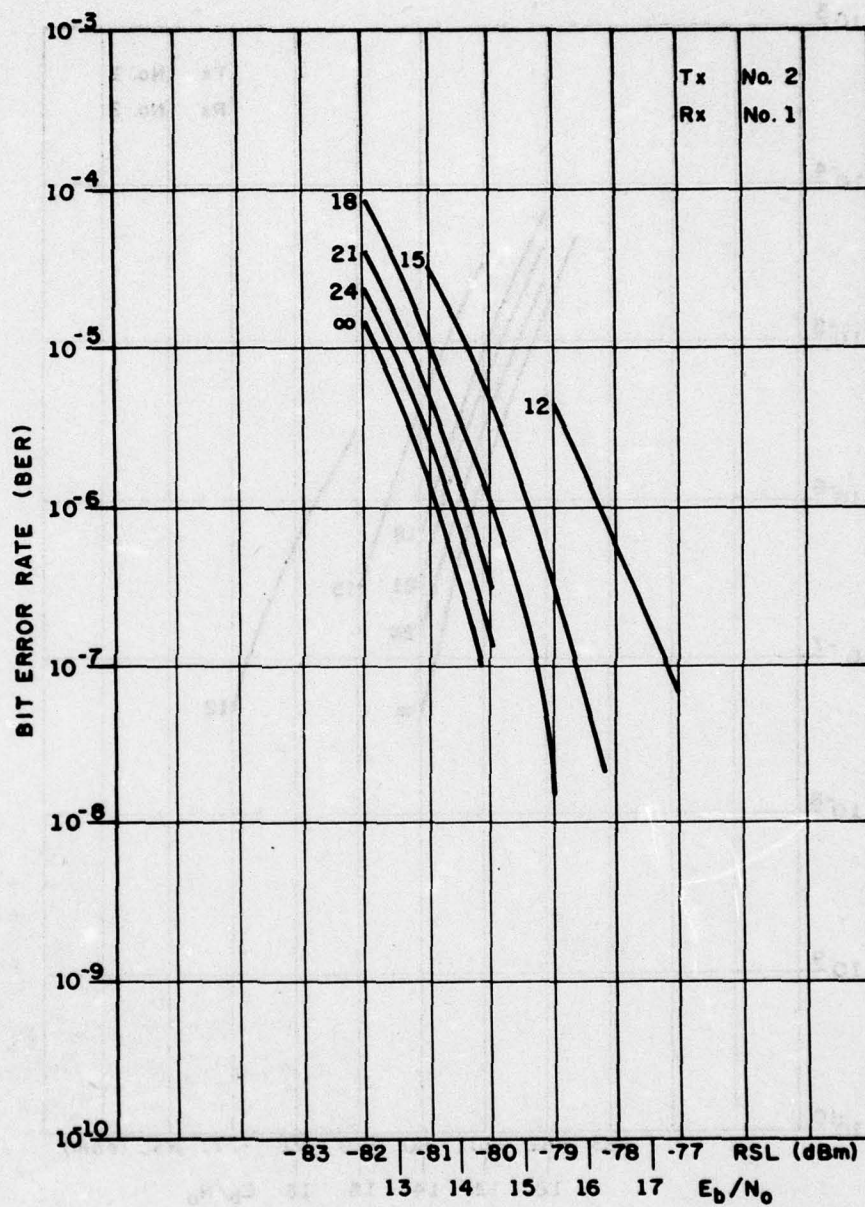


Figure 10 BER vs RSL for Various C/I Ratios (Tx2 to Rx1)

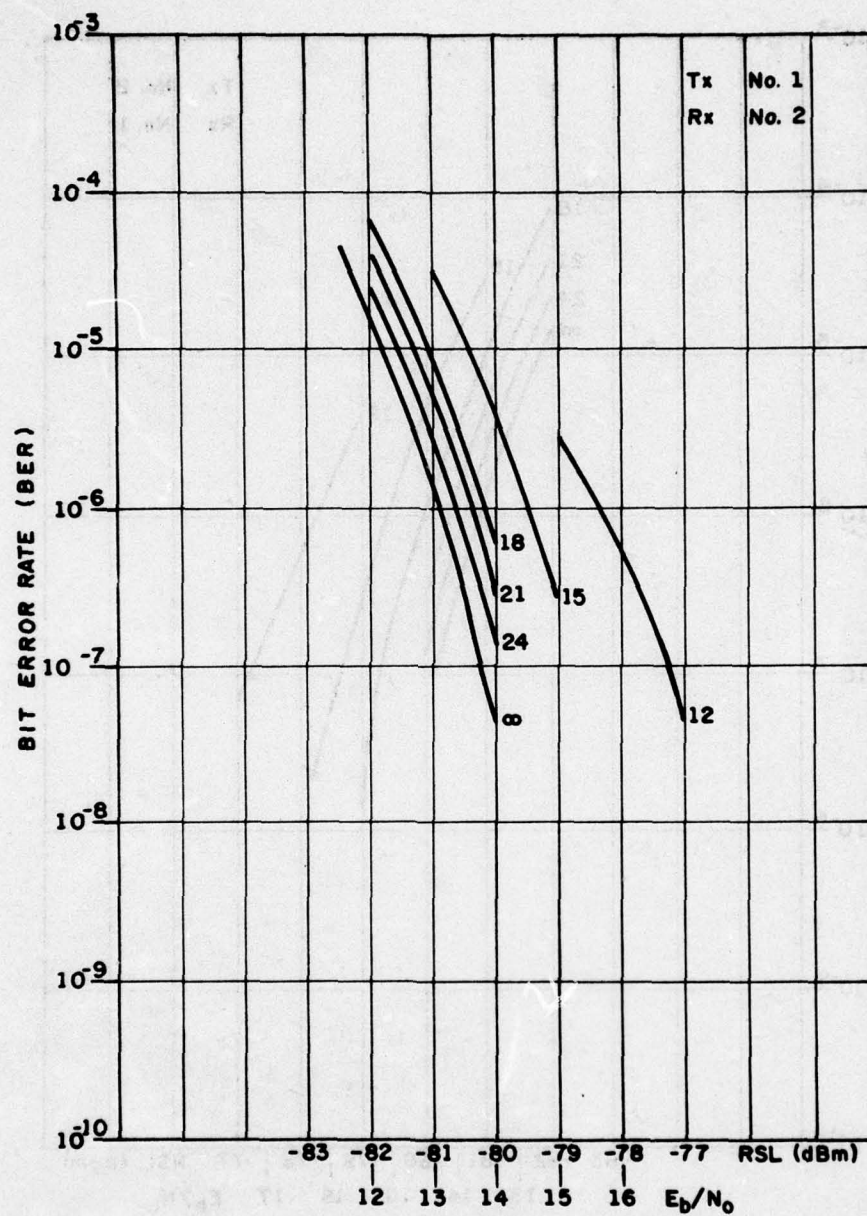


Figure 11 BER vs RSL for Various C/I Ratios

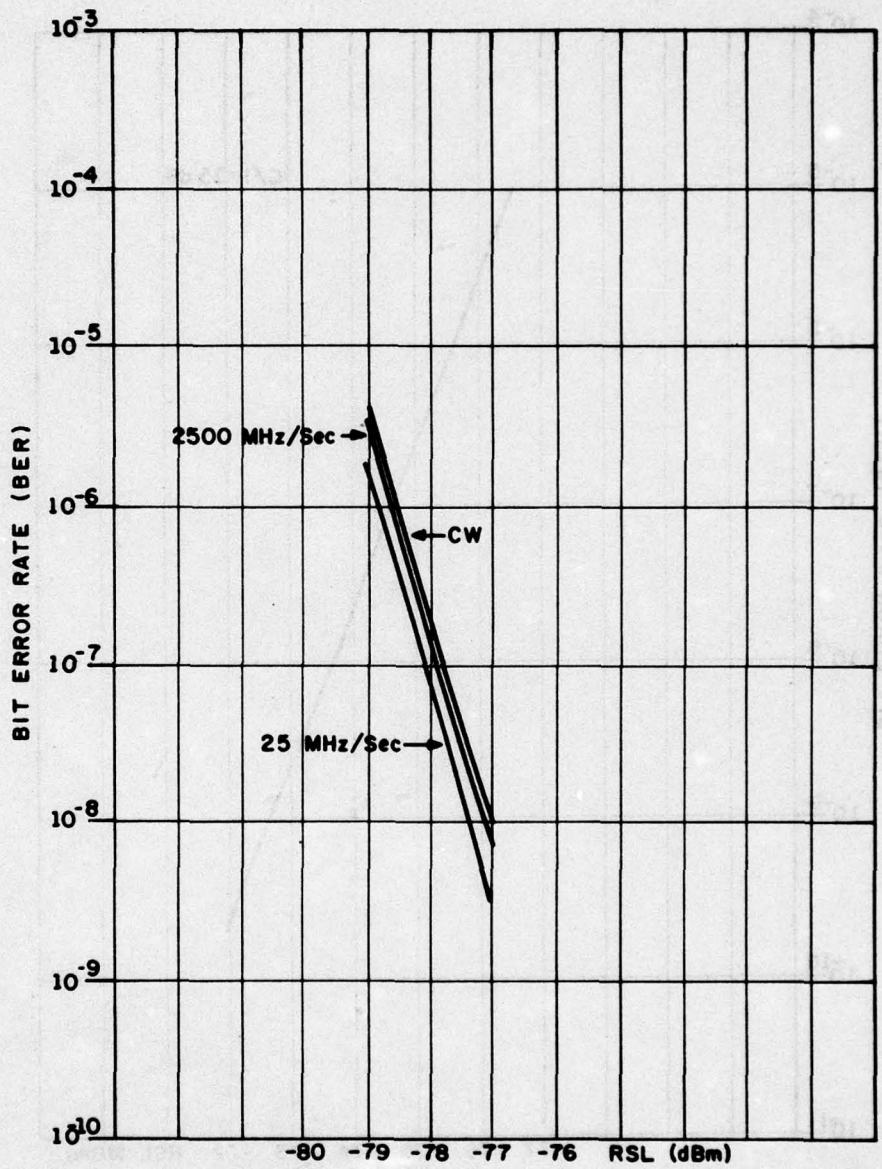


Figure 12 C/I Comparison by Sweep Rate

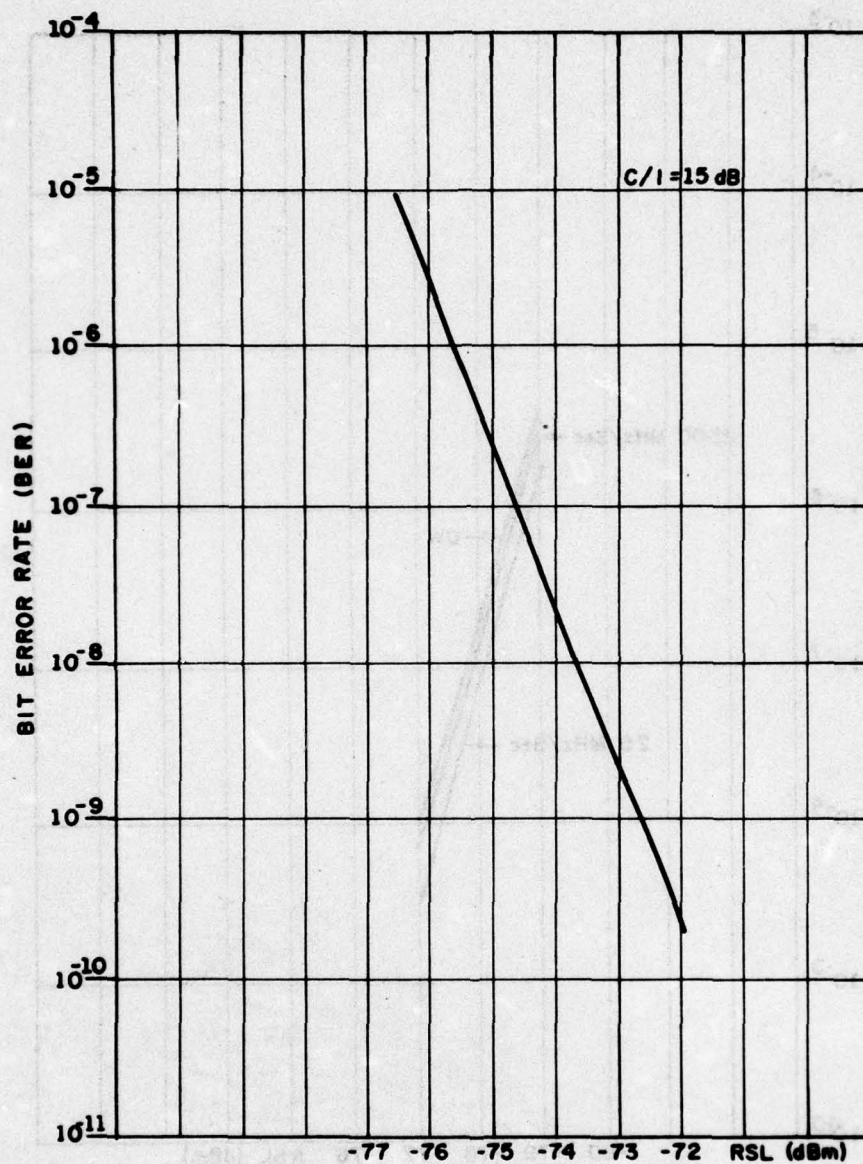
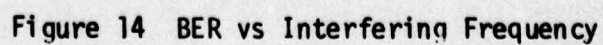


Figure 13 C/I Measurement at Higher RSL



3.3 Spectrum Evaluation.

3.3.1. The purpose of this test was to obtain measured power spectral density curves for use in evaluating filtering techniques. Rejection of out-of-band emissions to the level required by FCC Docket 19311 were analyzed, and the 99 percent power bandwidths calculated.

3.3.2 Procedure.

3.3.2.1 The equipment configuration for plotting spectral power distribution was basically the same as that employed for C/I testing in section 3.2.2, with the exception that a small amount of power was extracted from the directional coupler in the waveguide and displayed on a Hewlett-Packard 141T spectrum analyzer with the appropriate plug-in units. Figure 12 is a block diagram of the system. Hard copy of the spectrum was obtained through the use of an X-Y plotter driven by appropriate sources within the analyzer display unit.

3.3.2.2 In order to reference the displayed spectrum accurately to the appropriate FCC Docket 19311 requirements, total radiated power measurements of both modulated and unmodulated carriers also were made employing a Boonton 42 AD power meter and a 41-4B power sensor.

3.3.3 Results and Analysis.

3.3.3.1 The spectral tracings for this equipment were analyzed from the aspects of ascertaining the 99 per cent power bandwidths and compliance with the FCC Docket 19311 limitations. Each of the four bit rates were plotted through 45 MHz, 20 MHz, and 14 MHz bandwidth RF filters. Since filters for the two lower data rates were unavailable, the six plots involving 6.276 Mb/s and 1.544 Mb/s are included for information only as Appendix 1.

3.3.3.2 The first spectrums evaluated were those employing the 45 MHz RF filters in the transmitters. These filters provided for reverting to 600 channel FDM operation; however, figures 16 and 17 show that the 99 per cent power bandwidths do not fall within acceptable limits. Employing manual integration techniques to evaluate the spectra resulted in 99 per cent power bandwidths of 32 MHz and 24 Mhz respectively for the 19.804 Mb/s and 12.5526 Mb/s data rates.

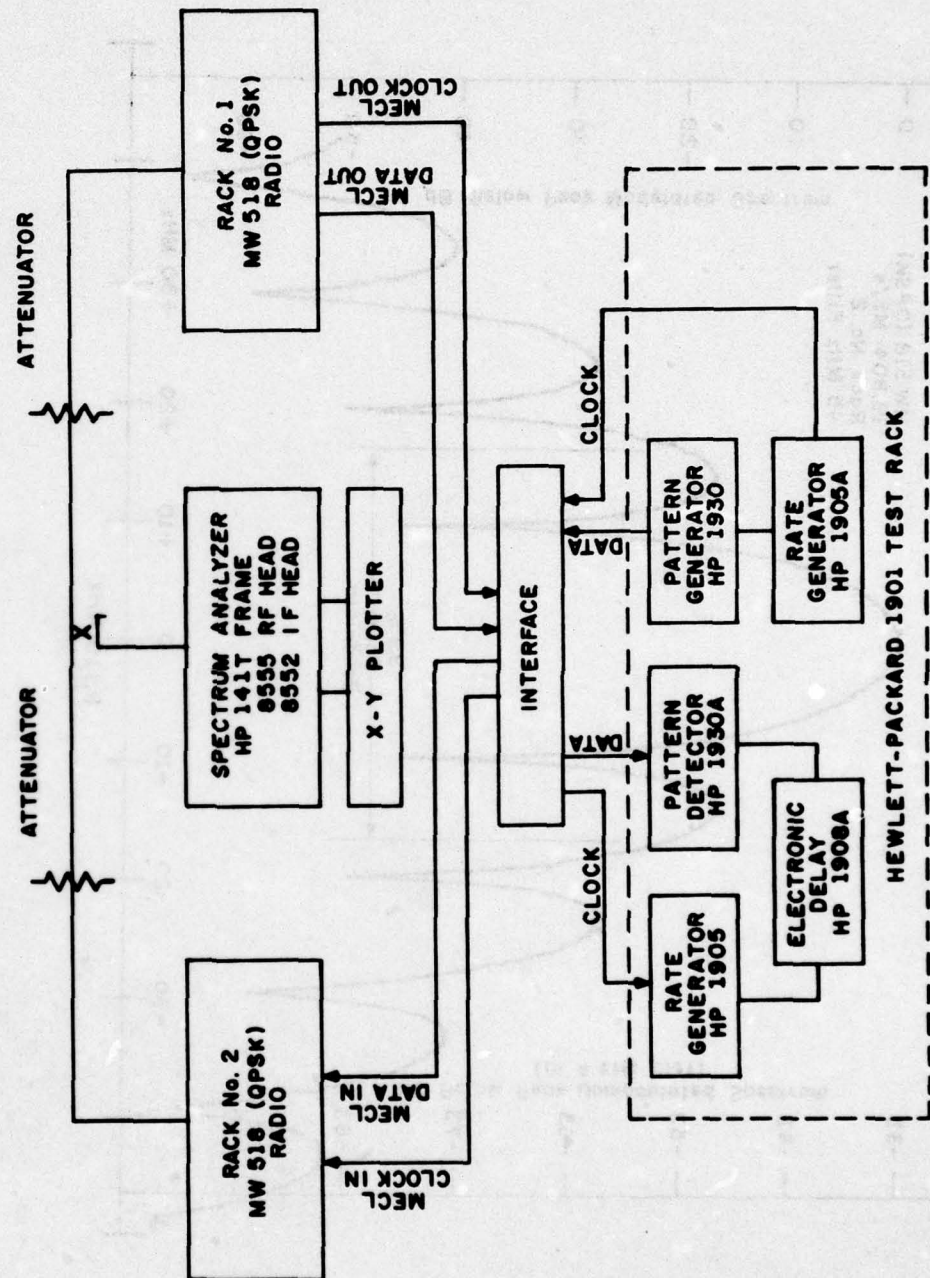


Figure 15 Power Spectral Density Test Configuration

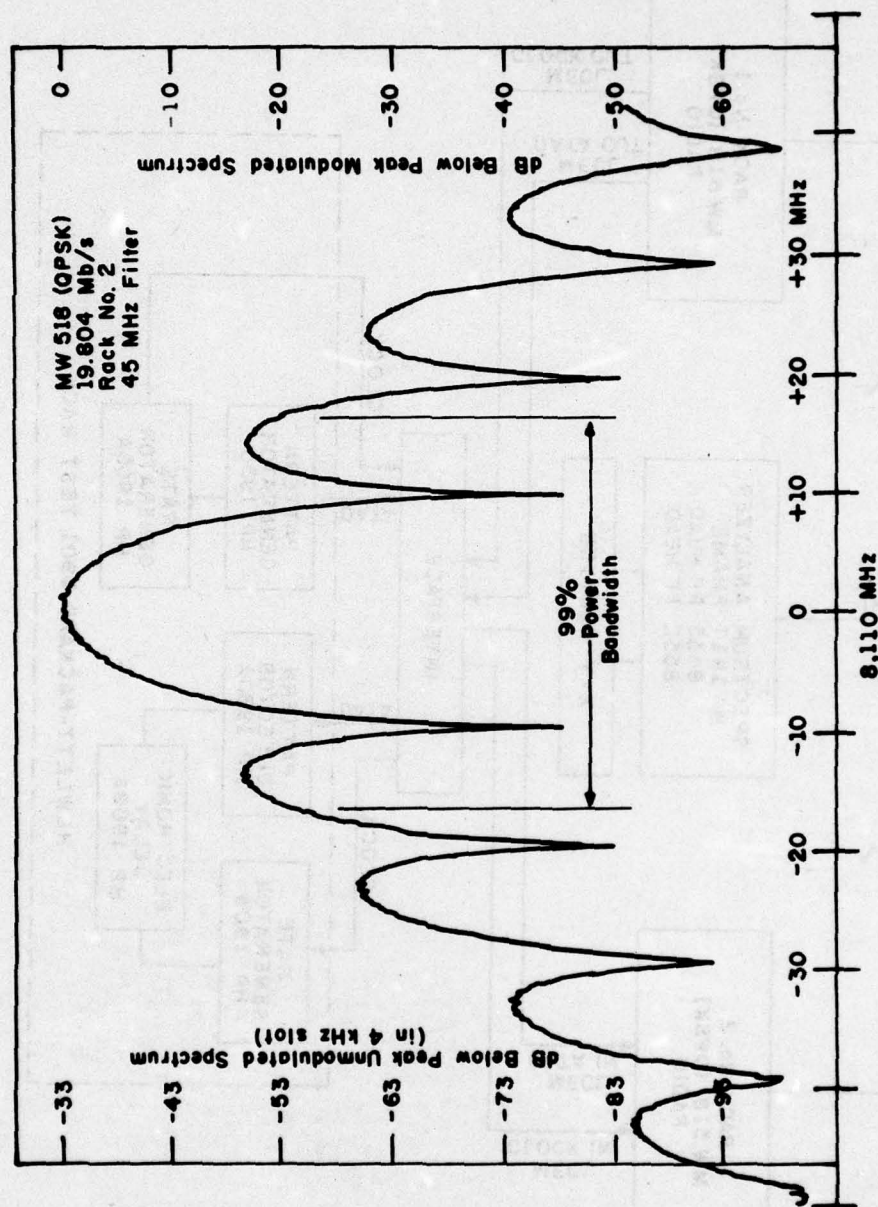


Figure 16 Power Spectral Density ($R = 19.8 \text{ Mb/s}$, $B = 45 \text{ MHz}$)

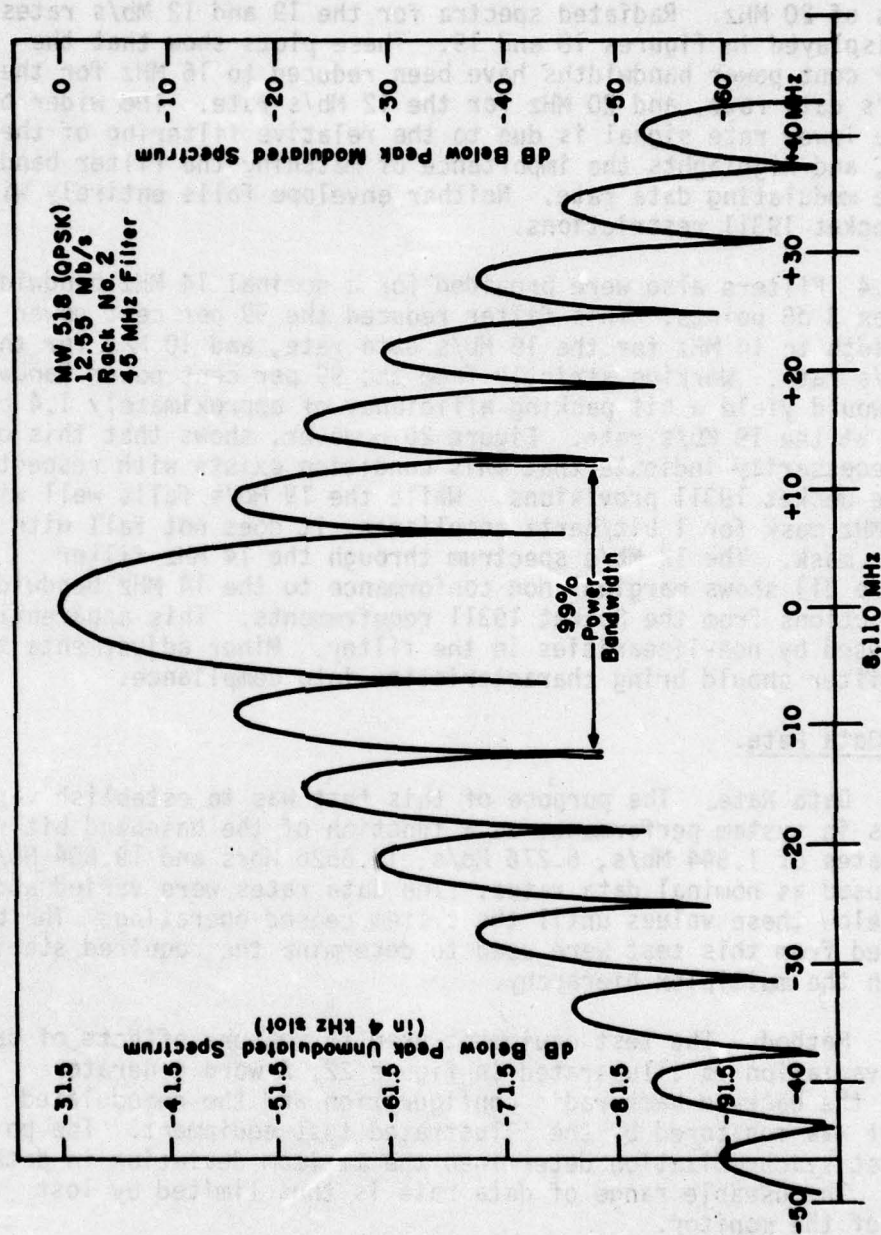


Figure 17 Power Spectral Density ($R = 12.6 \text{ Mb/s}$, $B = 45 \text{ MHz}$)

3.3.3.3 Increased concern over spectral emissions prompted the use of RF filters with narrower bandpass characteristics in November 1974. The first of these filters was aligned for a bandwidth between 3 dB points of 20 MHz. Radiated spectra for the 19 and 12 Mb/s rates are displayed in figures 18 and 19. These plots show that the 99 per cent power bandwidths have been reduced to 16 MHz for the 19 Mb/s data rate, and 20 MHz for the 12 Mb/s rate. The wider bandwidth of the lower rate signal is due to the relative filtering of the side lobes, and highlights the importance of matching the filter bandwidth to the modulating data rate. Neither envelope falls entirely within the Docket 19311 restrictions.

3.3.3.4 Filters also were provided for a nominal 14 MHz bandwidth between 3 dB points. This filter reduced the 99 per cent power bandwidth to 14 MHz for the 19 Mb/s data rate, and 10 MHz for the 12 Mb/s rate. Working strictly from the 99 per cent power bandwidths then would yield a bit packing efficiency of approximately 1.4 bits/hertz at the 19 Mb/s rate. Figure 20 however, shows that this does not necessarily indicate that this condition exists with respect to the Docket 19311 provisions. While the 19 Mb/s falls well within a 20 MHz mask for 1 bit/hertz compliance, it does not fall with a 14 MHz mask. The 12 Mb/s spectrum through the 14 MHz filter (figure 21) shows marginal non conformance to the 14 MHz bandwidth restrictions from the Docket 19311 requirements. This apparently is caused by non-linearities in the filter. Minor adjustments to the filter should bring characteristics into compliance.

3.4 Data Rate.

3.4.1 Data Rate. The purpose of this test was to establish variations in system performance as a function of the baseband bit rate. Bit rates of 1.544 Mb/s, 6.276 Mb/s, 12.5526 Mb/s and 19.804 Mb/s were used as nominal data rates. The data rates were varied above and below these values until the system ceased operating. The data derived from this test were used to determine the required stability within the multiplex hierarchy.

3.4.2 Method. The test equipment used to measure effects of data rate variation is illustrated in figure 22. A word generator drove the back-to-back radio configuration and the demodulated output was monitored by the illustrated test equipment. The point of last synchronization determined the maximum deviation in data rate. The useable range of data rate is thus limited by lost lock of the monitor.

3.4.3 Results and Analysis. Using an external clock on the 1.544 Mb/s nominal bit rate, the radio did not operate at precisely 1.544 Mb/s. The usable variable in data rate was from 1.544450 Mb/s to 1.545384 Mb/s in the transmit number one to receive number two mode. In the second mode, transmit number two to receive number 1, the usable range was from 1.544490 Mb/s to 1.545384 Mb/s.

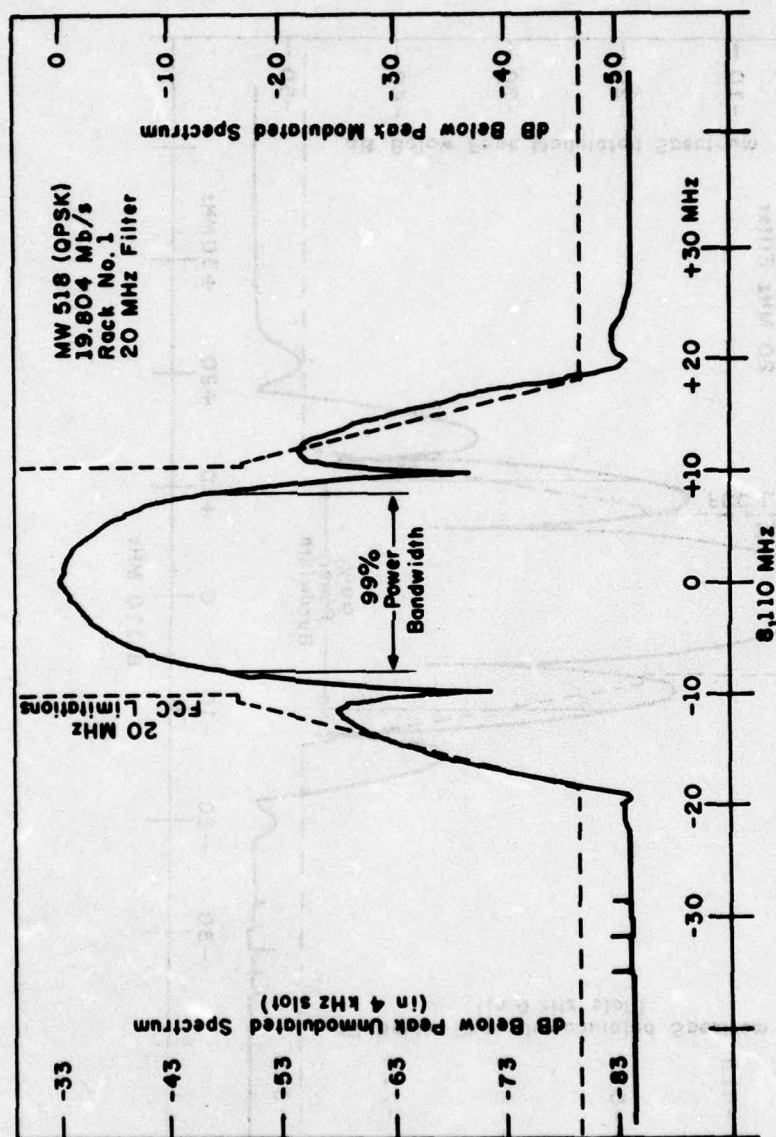


Figure 18 Power Spectrum and FCC Mask ($R = 19.8 \text{ Mb/s}$, $B = 20 \text{ MHz}$)

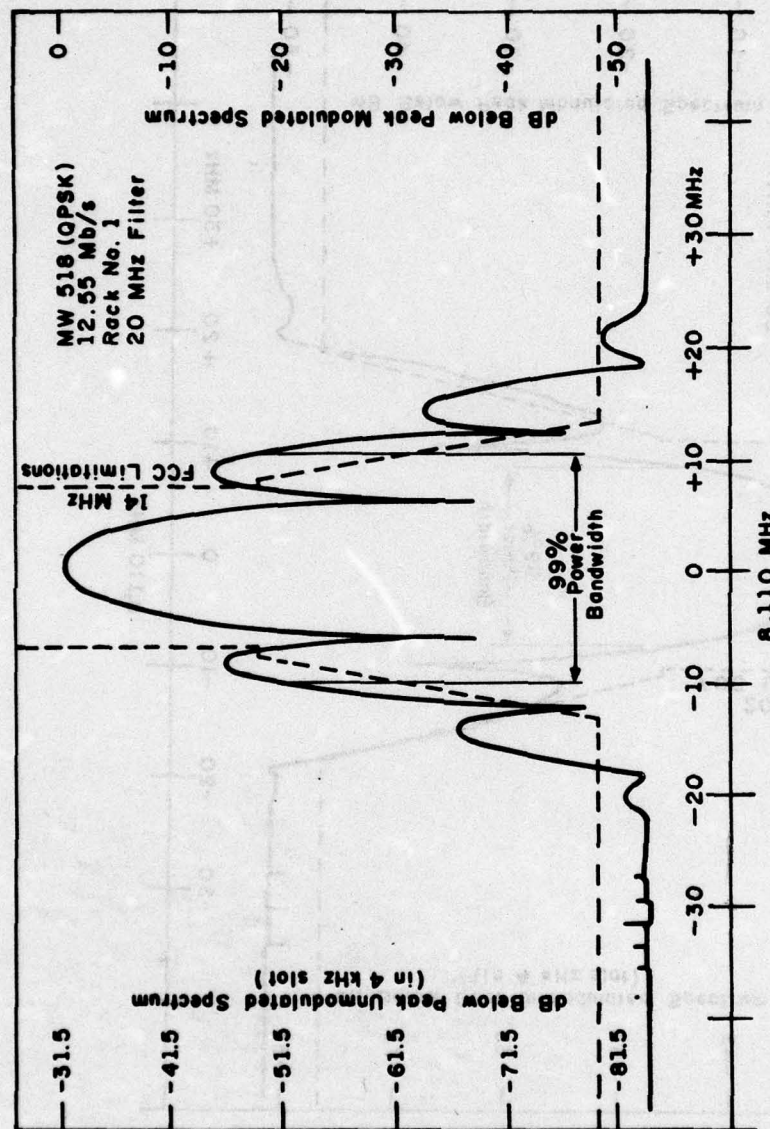


Figure 19 Power Spectrum and FCC Mask ($R = 12.6 \text{ Mb/s}$, $B = 20 \text{ MHz}$)

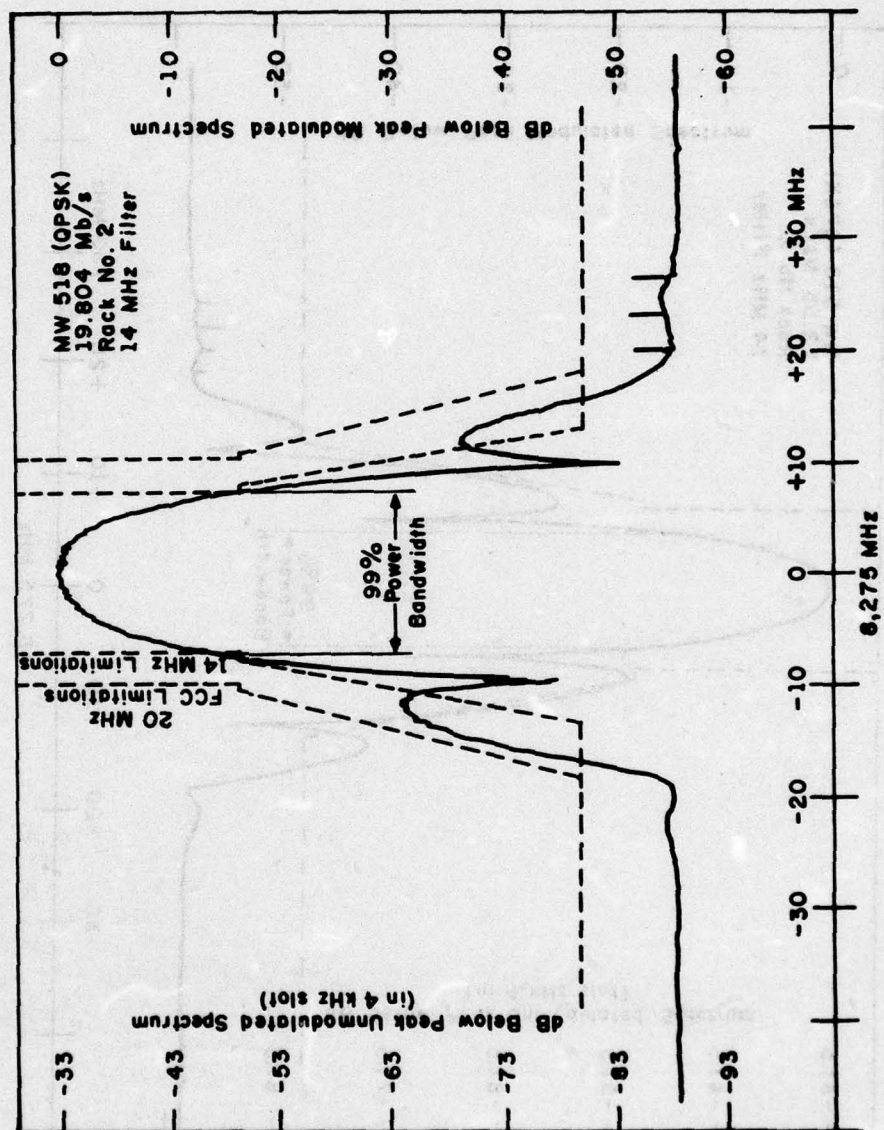


Figure 20 Power Spectrum and FCC Mask ($R = 19.8 \text{ Mb/s}$, $B = 14 \text{ MHz}$)

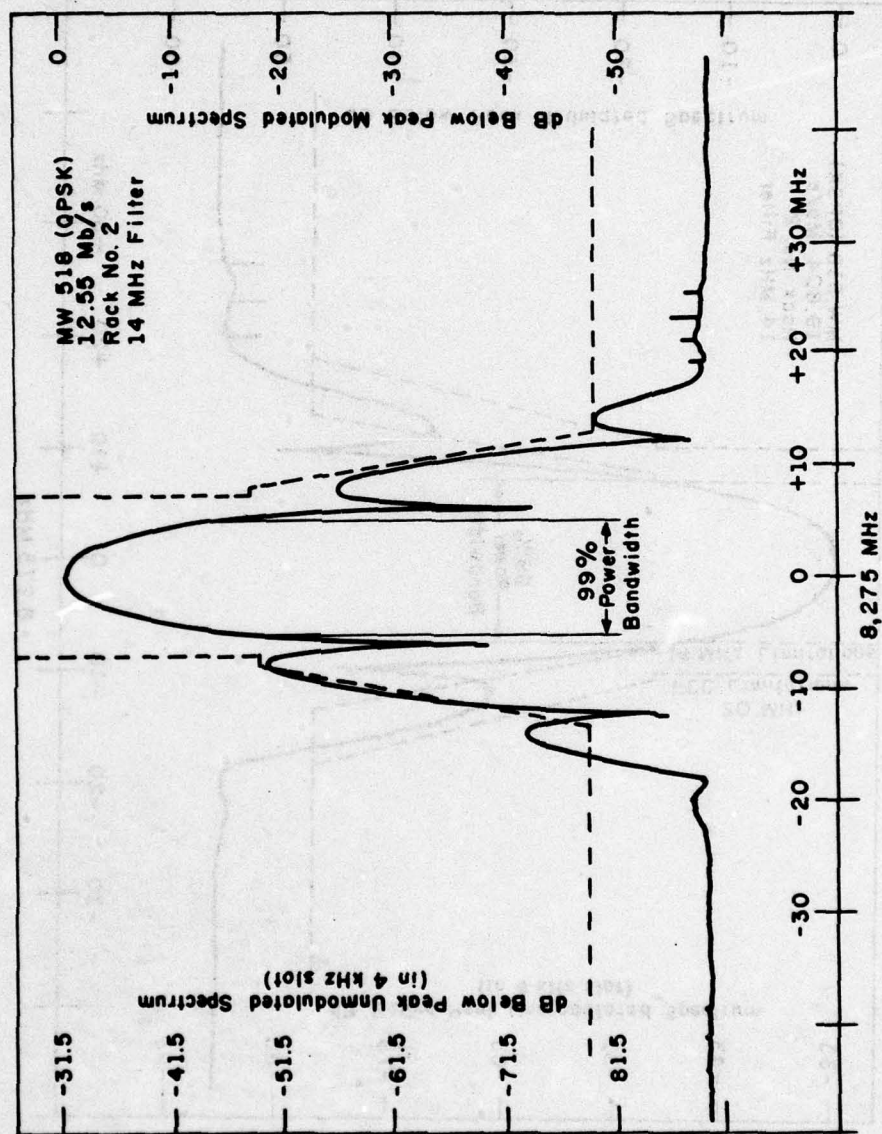


Figure 21 Power Spectrum and FCC Mask ($R = 12.6 \text{ Mb/s}$, $B = 14 \text{ MHz}$)

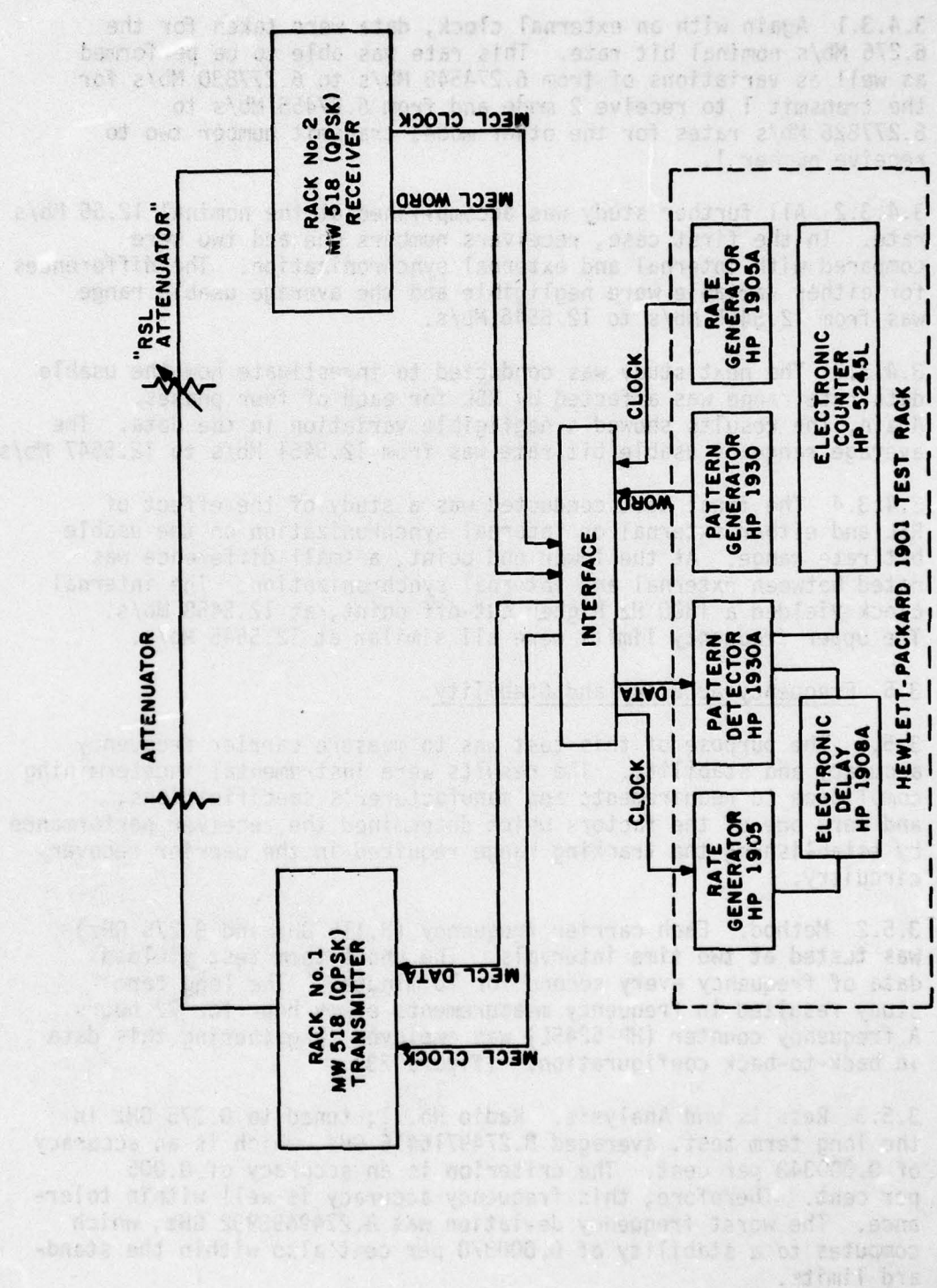


Figure 22 Data Rate Variation Test Configuration

3.4.3.1 Again with an external clock, data were taken for the 6.276 Mb/s nominal bit rate. This rate was able to be performed as well as variations of from 6.274548 Mb/s to 6.277830 Mb/s for the transmit 1 to receive 2 mode and from 6.27455 Mb/s to 6.277826 Mb/s rates for the other mode, transmit number two to receive number 1.

3.4.3.2 All further study was accomplished at the nominal 12.55 Mb/s rate. In the first case, receivers numbers one and two were compared with internal and external synchronization. The differences for either variable were negligible and the average usable range was from 12.5455 Mb/s to 12.5546 Mb/s.

3.4.3.3 The next study was conducted to investigate how the usable data rate range was affected by RSL for each of four phases. Again, the results showed a negligible variation in the data. The average range of usable bit rate was from 12.5451 Mb/s to 12.5547 Mb/s.

3.4.3.4 The final test conducted was a study of the effect of RSL and either external or internal synchronization on the usable bit rate range. At the lower end point, a small difference was noted between external and internal synchronization. The internal clock yielded a 1300 Hz higher cut-off point, at 12.5458 Mb/s. The upper frequency limits were all similar at 12.5545 Mb/s.

3.5 Frequency Accuracy and Stability.

3.5.1 The purpose of this test was to measure carrier frequency accuracy and stability. The results were instrumental indetermining compliance to requirements and manufacturer's specifications, and were one of the factors which determined the receiver performance by establishing the tracking range required in the carrier recovery circuitry.

3.5.2 Method. Each carrier frequency (8.110 GHz and 8.275 GHz) was tested at two time intervals. The short term test yielded data of frequency every second for 10 minutes. The long term study resulted in frequency measurements every hour for 72 hours. A frequency counter (HP-5245L) was employed in gathering this data in back-to-back configuration. (figure 23).

3.5.3 Results and Analysis. Radio No. 1, tuned to 8.275 GHz in the long term test, averaged 8.2749716416 GHz, which is an accuracy of 0.000343 per cent. The criterion is an accuracy of 0.005 per cent. Therefore, this frequency accuracy is well within tolerance. The worst frequency deviation was 8.2749693992 GHz, which computes to a stability of 0.000370 per cent also within the standard limits.

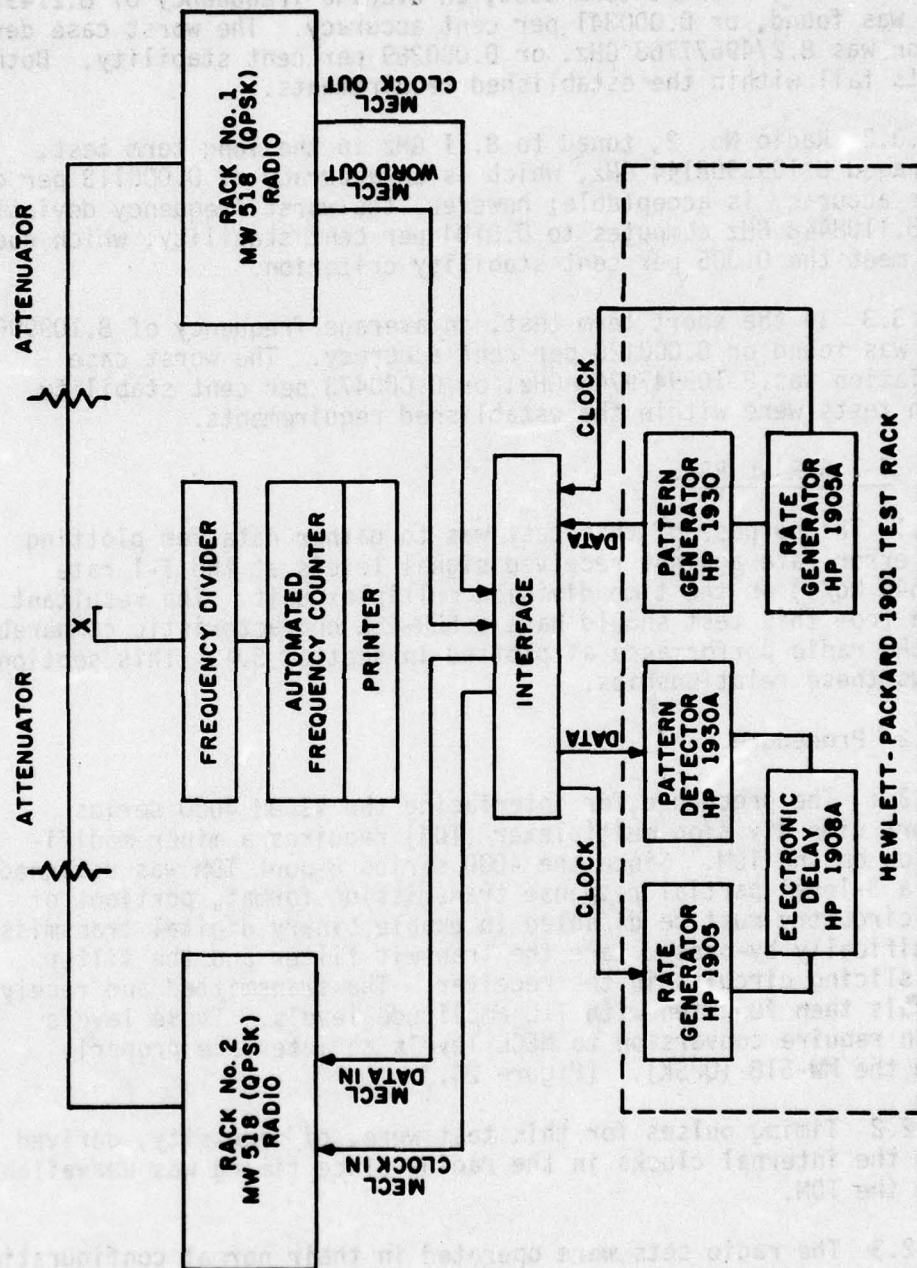


Figure 23 Frequency Stability Test Configuration

3.5.3.1 In the short term test, an average frequency of 8.274971742 GHz was found, or 0.000341 per cent accuracy. The worst case deviation was 8.2749677768 GHz, or 0.000389 per cent stability. Both tests fall within the established requirements.

3.5.3.2 Radio No. 2, tuned to 8.11 GHz in the long term test, averaged 8.1099908144 GHz, which is an accuracy of 0.000113 per cent. This accuracy is acceptable; however, the worst frequency deviation of 8.1108448 GHz computes to 0.0104 per cent stability, which does not meet the 0.005 per cent stability criterion.

3.5.3.3 In the short term test, an average frequency of 8.109990304 GHz was found or 0.000120 per cent accuracy. The worst case deviation was 8.1099479744 GHz, or 0.000473 per cent stability. Both tests were within the established requirements.

3.6 T-1 BER vs RSL.

3.6.1 The purpose of this test was to gather data for plotting bit error rate against received signal levels at the T-1 rate (1.544 Mb/s) in the time division multiplex unit. The resultant data from this test should have a BER-RSL characteristic comparable to the radio performance as plotted in section 3.1. This section shows these relationships.

3.6.2 Procedure.

3.6.2.1 The procedure for interfacing the VICOM 4000 series 8-port time division multiplexer (TDM) requires a minor modification on the TDM. Since the 4000 series 8-port TDM was designed for a 3-level partial response transmission format, portions of the circuitry must be disabled to enable binary digital transmission; specifically by-passed are the transmit filter and the filter and slicing circuits in the receiver. The transmitted and received signals then function with TTL amplitude levels. These levels again require conversion to MECL levels to interface properly with the MW-518 (QPSK). (Figure 24.)

3.6.2.2 Timing pulses for this test were, of necessity, derived from the internal clocks in the radios since timing was unavailable from the TDM.

3.6.2.3 The radio sets were operated in their normal configuration for the 12.5526 Mb/s rate. The desired data transmission flow was from the Rack No. 2 transmitter to the Rack No. 1 receiver. Random data were transmitted in the reverse direction to simulate an operating system. Simulated path attenuation was employed using a combination of fixed and variable waveguide attenuators.

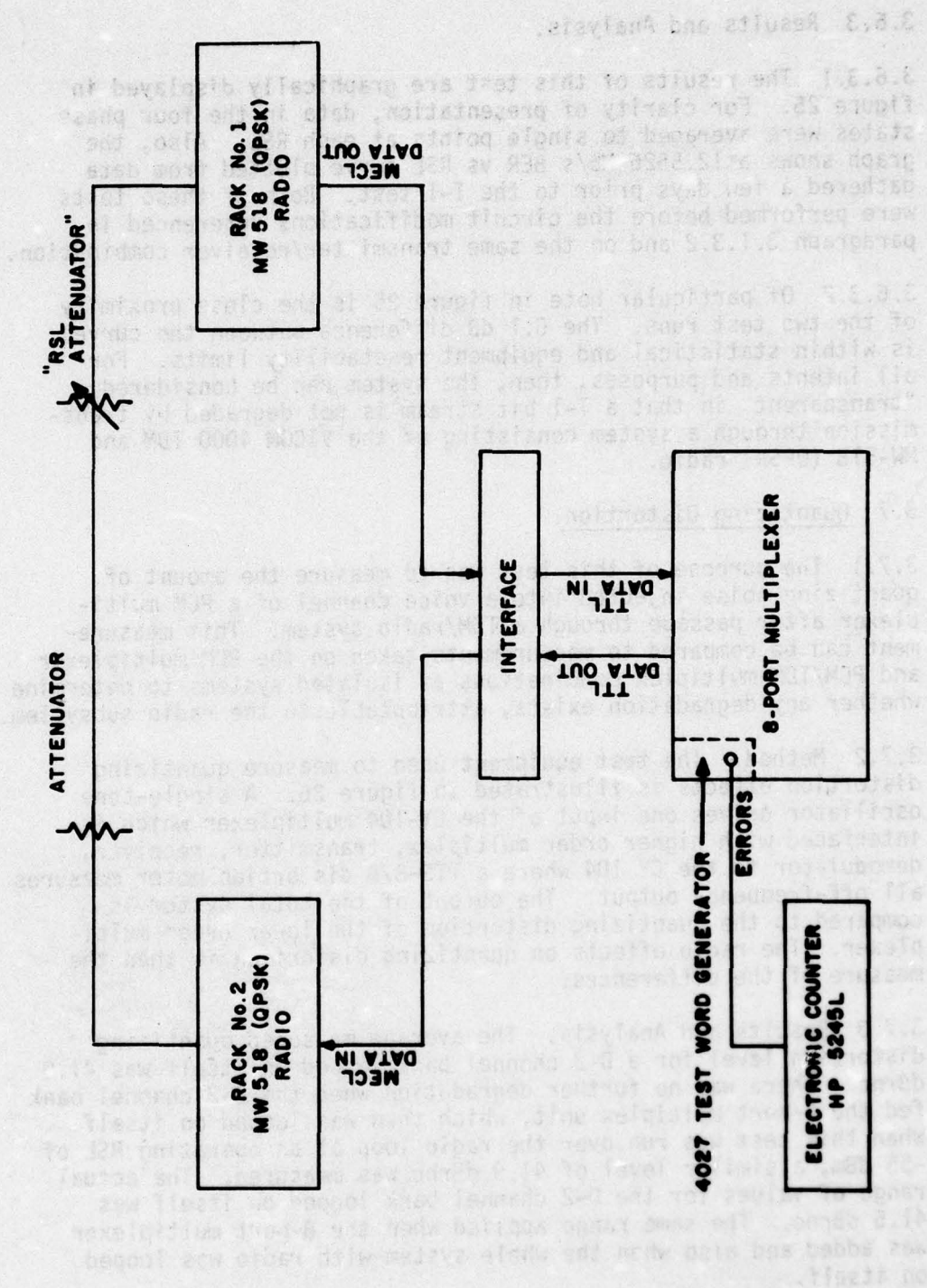


Figure 24 T-1 BER vs RSL Test Configuration

3.6.3 Results and Analysis.

3.6.3.1 The results of this test are graphically displayed in figure 25. For clarity of presentation, data in the four phase states were averaged to single points at each RSL. Also, the graph shows a 12.5526 Mb/s BER vs RSL curve plotted from data gathered a few days prior to the T-1 test. Both of these tests were performed before the circuit modifications referenced in paragraph 3.1.3.2 and on the same transmitter/receiver combination.

3.6.3.2 Of particular note in figure 25 is the close proximity of the two test runs. The 0.1 dB difference between the curves is within statistical and equipment resetability limits. For all intents and purposes, then, the system can be considered "transparent" in that a T-1 bit stream is not degraded by transmission through a system consisting of the VICOM 4000 TDM and MW-518 (QPSK) radio.

3.7 Quantizing Distortion.

3.7.1 The purpose of this test was to measure the amount of quantizing noise injected into a voice channel of a PCM multiplexer after passage through a TDM/radio system. This measurement can be compared to measurements taken on the PCM multiplexer and PCM/TDM multiplex combinations as isolated systems to determine whether any degradation exists, attributable to the radio subsystem.

3.7.2 Method. The test equipment used to measure quantizing distortion effects is illustrated in figure 26. A single-tone oscillator drives one input of the CY-104 multiplexer which is interfaced with higher order multiplex, transmitter, receiver, demodulator to the CY 104 where a TTS-37B distortion meter measures all off-frequency output. The output of the total system is compared to the quantizing distortion of the lower order multiplexer. The radio effects on quantizing distortion is then the measure of the differences.

3.7.3 Results and Analysis. The average measured quantizing distortion level for a D-2 channel bank looped on itself was 41.9 dBrnc. There was no further degradation when the D-2 channel bank fed the 8-port multiplex unit, which then was looped on itself. When this test was run over the radio loop at an operating RSL of -55 dBm, a similar level of 41.9 dBrnc was measured. The actual range of values for the D-2 channel bank looped on itself was 41.5 dBrnc. The same range applied when the 8-port multiplexer was added and also when the whole system with radio was looped on itself.

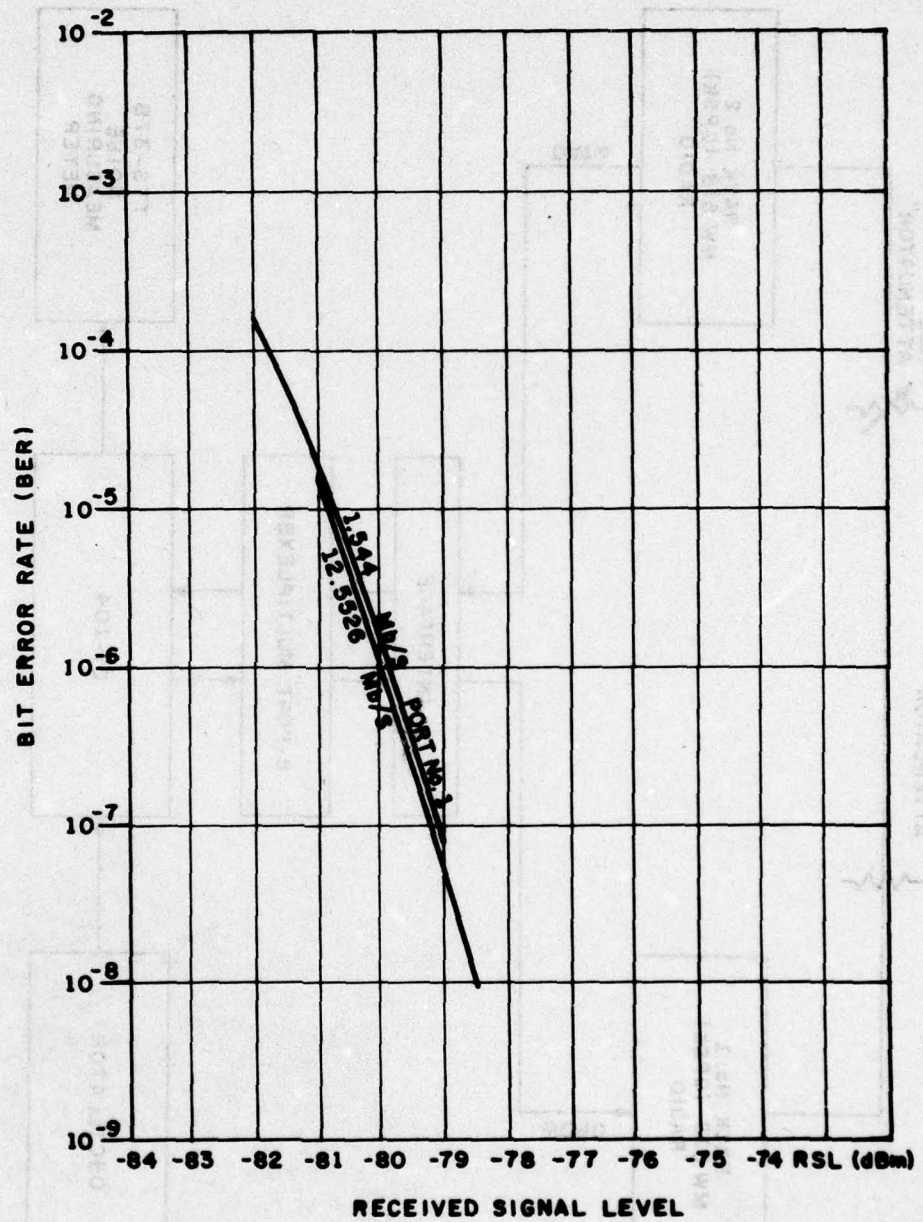


Figure 25 Comparison of T-1 to Radio System Performance

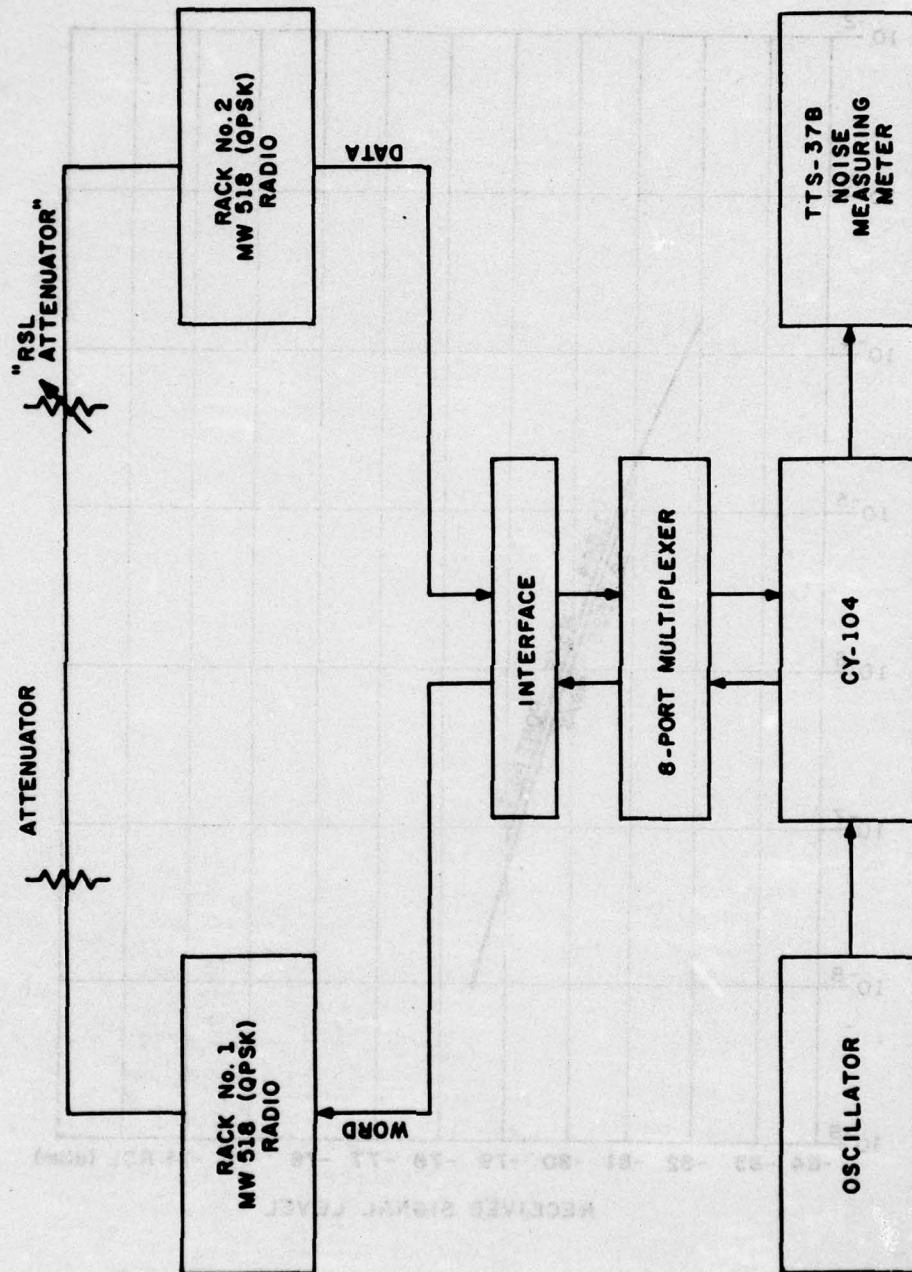


Figure 26 Quantizing Distortion and Crosstalk Test Configuration

3.8 Crosstalk.

3.8.1 The purpose of this test was to measure crosstalk between adjacent channels in a PCM multiplexer when transmitted through the MW-518 (QPSK) radio set. The data gathered was compared to tests performed on the PCM multiplexer and PCM/TDM multiplex combinations to determine whether the radio system causes degradation to this specification.

3.8.2 Method. The test equipment used to measure crosstalk is illustrated in figure 26. A single tone oscillator drives one input of the CY-104 multiplexer which is interfaced with higher order multiplexer, transmitter, receiver, demodulator to the CY-104 where a TTS-37B distortion meter measures the output of the adjacent channel. The output of the adjacent channel with the multiplexer looped on itself is compared to the overall system output. The radio effects on adjacent channel crosstalk is the measure of the difference.

3.8.3 Results and Analysis. The D-2 channel bank was looped on itself to measure crosstalk levels. All channels fell within the 25 dBrnc maximum ranging from +0 dBrnc to +16.7 dBrnc. Next, the D-2 channel bank fed the 8-port multiplexer, which was looped on itself. Again, the 25 dBrnc maximum was met with a range of -1 dBrnc to 17.5 dBrnc. Finally the D-2 multiplex and radio were connected and looped back to measure crosstalk levels. A range of -2 dBrnc to 17.2 dBrnc was recorded, again within the stated criterion. Thus, the higher order multiplexer and radio units add no significant crosstalk to the system.

3.9 Orderwire Signal-to-Noise.

3.9.1 The purpose of this test was to gather information on the performance of the service channel (orderwire) by measuring the signal-to-noise ratio at various signal levels and bit rates.

3.9.2 Method. The test equipment used to measure orderwire performance is illustrated in figure 27. A 1000 Hz single-tone drove the transmitter and a TTS-37B noise measuring meter monitored the output of the receiver in rack No. 1. Various received signal levels were recorded as well as the point of system failure. The three data rates also were investigated.

3.9.3 Results and Analysis. Employing the procedure in paragraph 3.9.2, the resultant data shows that a minimum signal-to-noise ratio of 40.4 dB is realizable in the orderwire channel. Since the orderwire FM's the RF carrier as the mission data stream

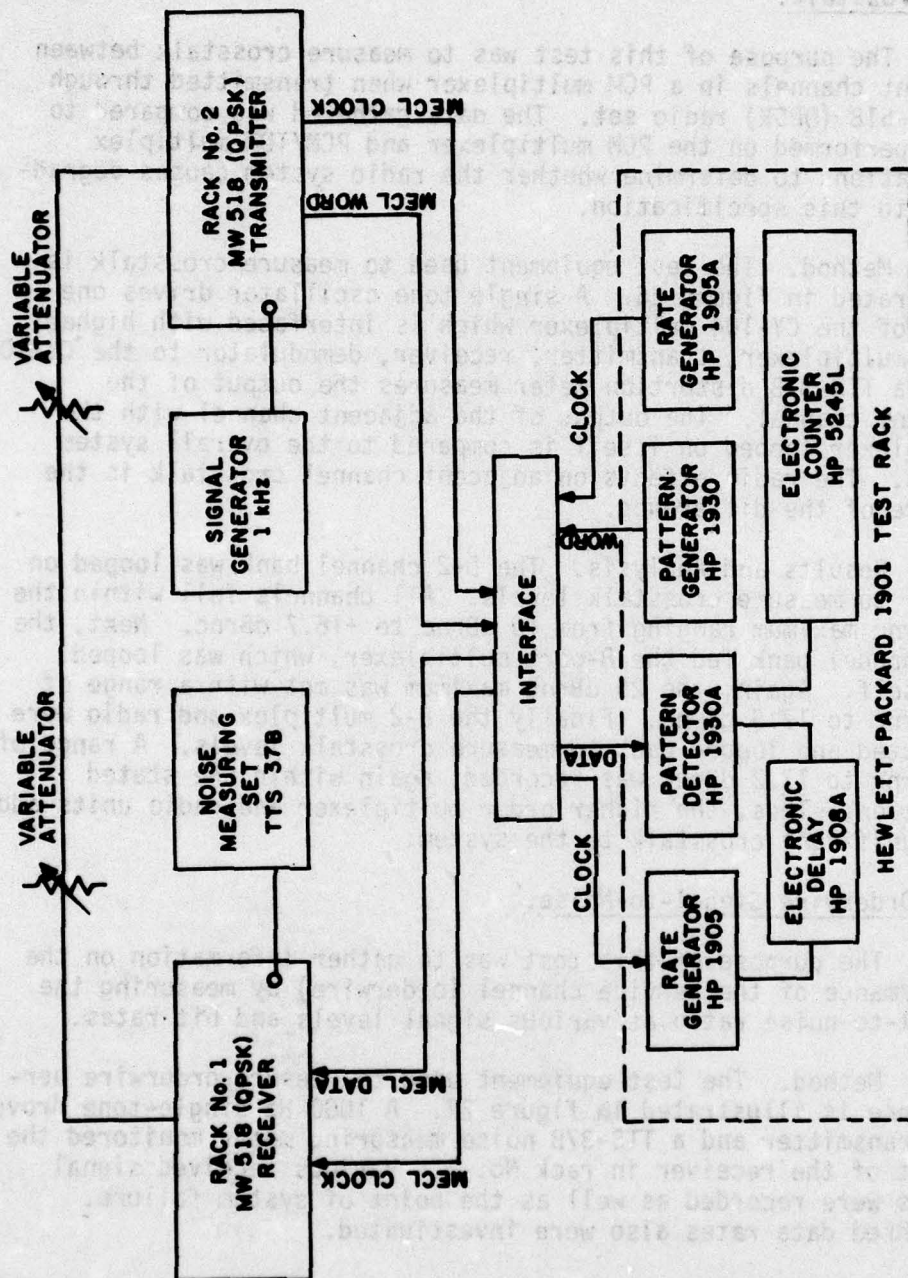


Figure 27 Orderwire Test Configuration

phase modulates the same signal, degradation in the signal-to-noise ratio of the 300 Hz to 8 kHz orderwire channel is expected when the mission data rate is lowered. This was measured when the data rates were lowered to 6.276 and 1.544 Mb/s; however, all of the reduction in signal-to-noise cannot be attributed to the lower data rates.

3.9.3.1 The procedure established by Collins for deviation adjustment of the orderwire signals specified an amplitude level which is close to the optimum for the 12.55 Mb/s data rate. The amplitude then remained the same for the other data rates, implying that the orderwire system is comparatively under-deviated at the 19.804 Mb/s rate, and over-deviated at the 6.276 and 1.544 Mb/s rates. Both of these conditions contribute to the degraded performance at data rates other than 12.55 Mb/s.

3.9.3.2 With optimal settings of the orderwire deviation for each bit rate, the signal-to-noise probably would reduce as the data rate is reduced with the greatest increment in degradation being between the 6.276 and 1.544 Mb/s rates.

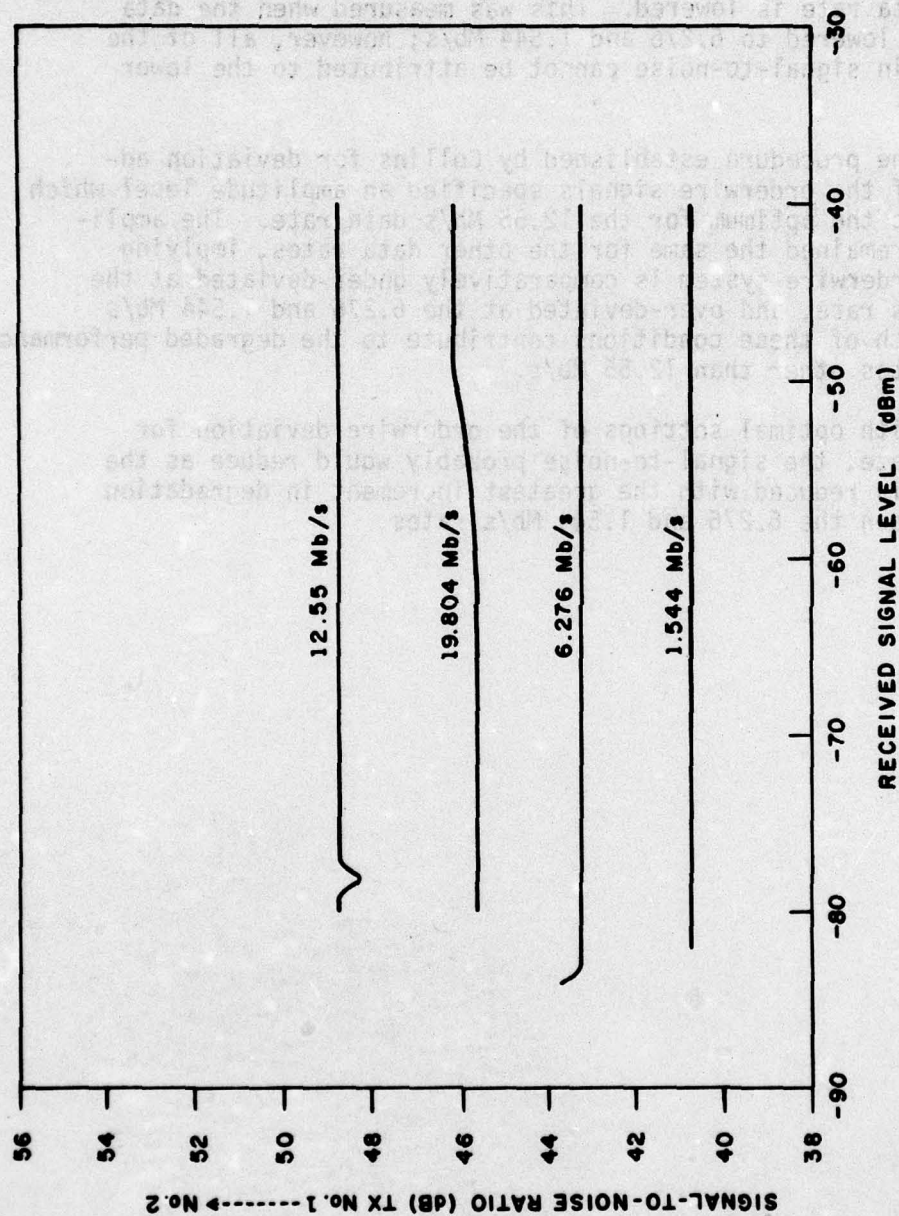


Figure 28 Orderwire Performance (Tx 1 to Rx 2)

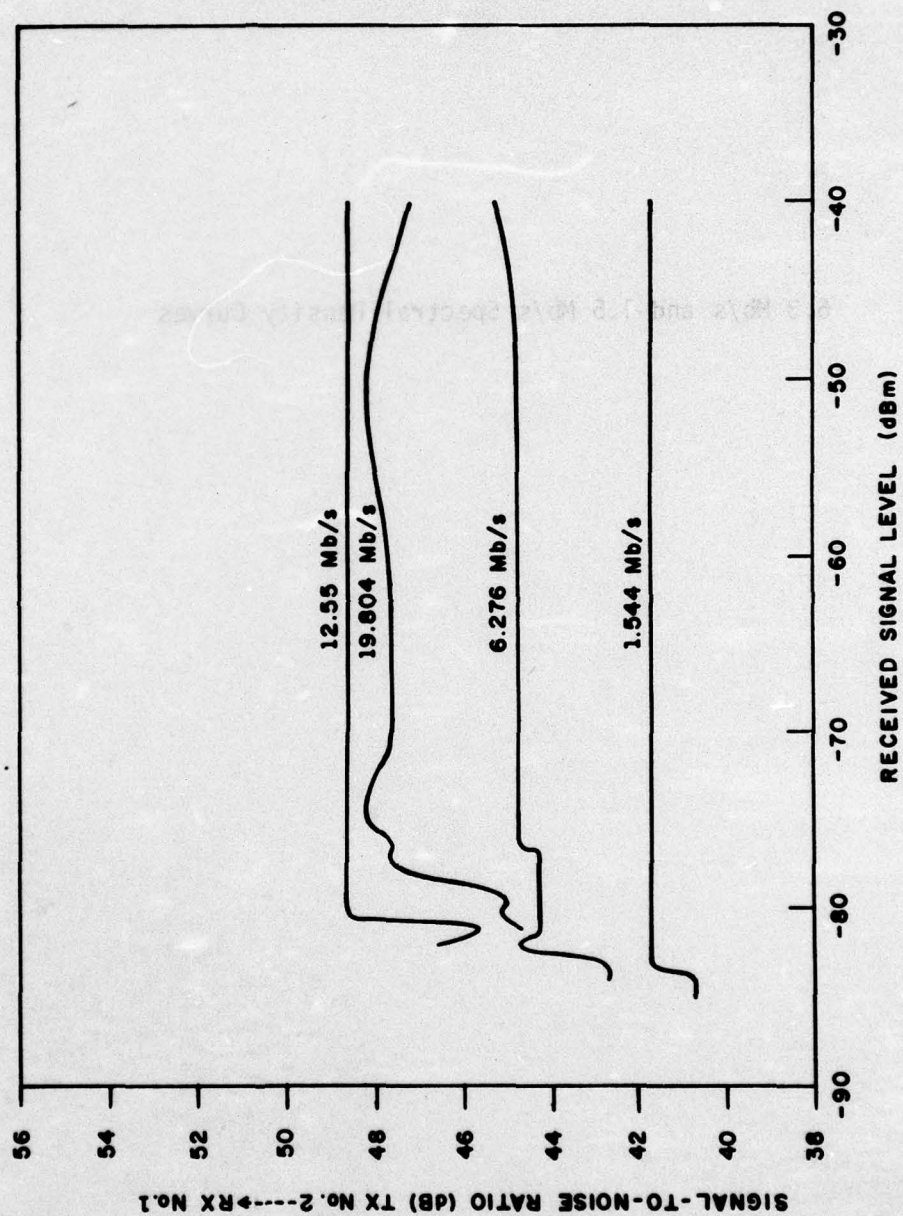
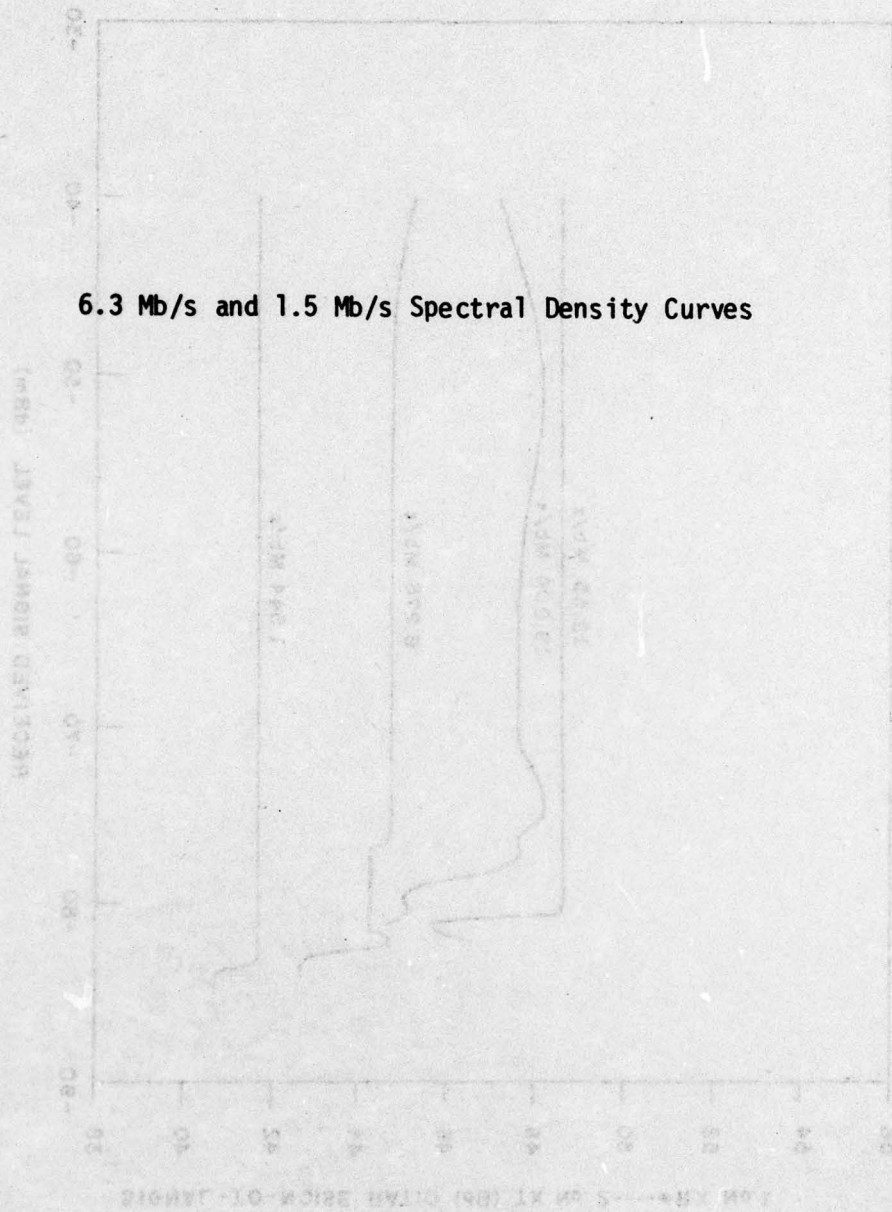


Figure 29 Orderwire Performance (Tx 2 to Rx 1)

APPENDIX 1

6.3 Mb/s and 1.5 Mb/s Spectral Density Curves



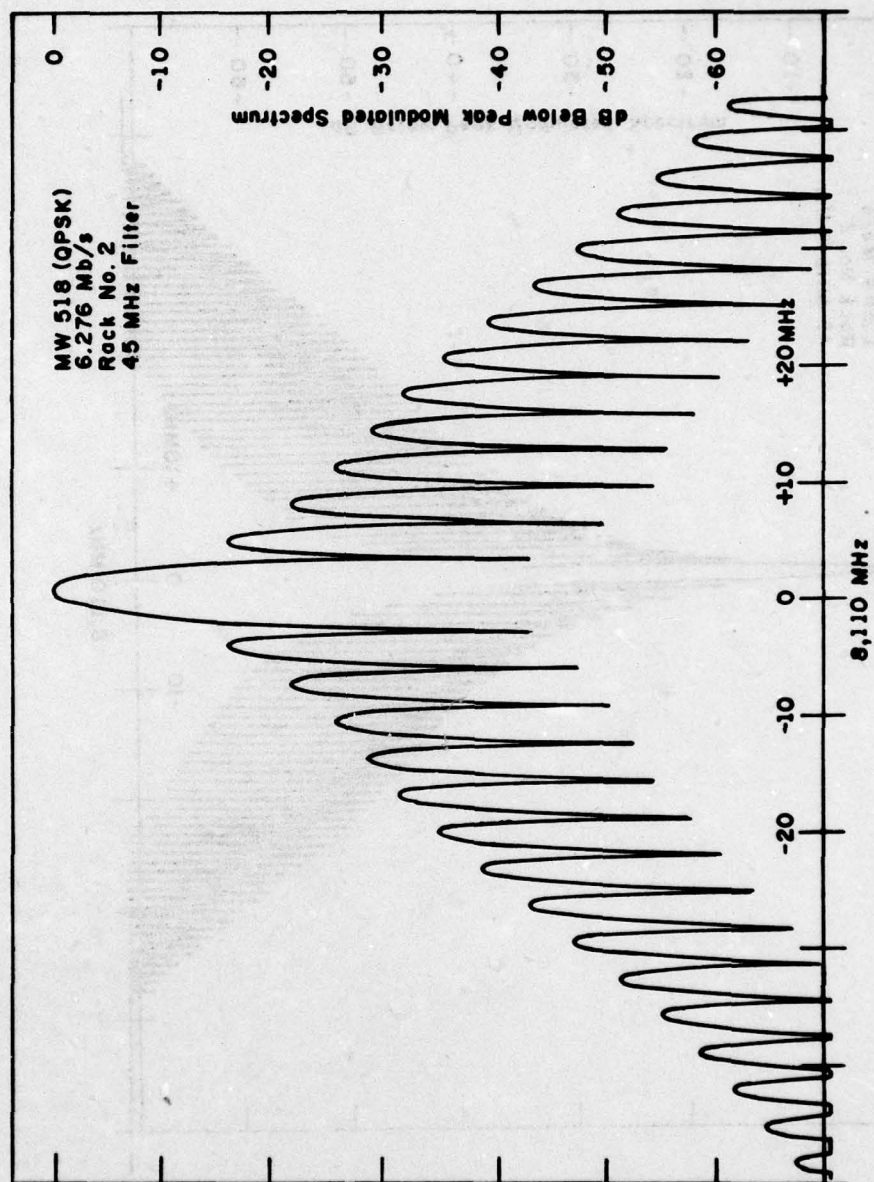


Figure 30 Power Spectral Density (R = 6.3 Mb/s, B = 45 MHz)

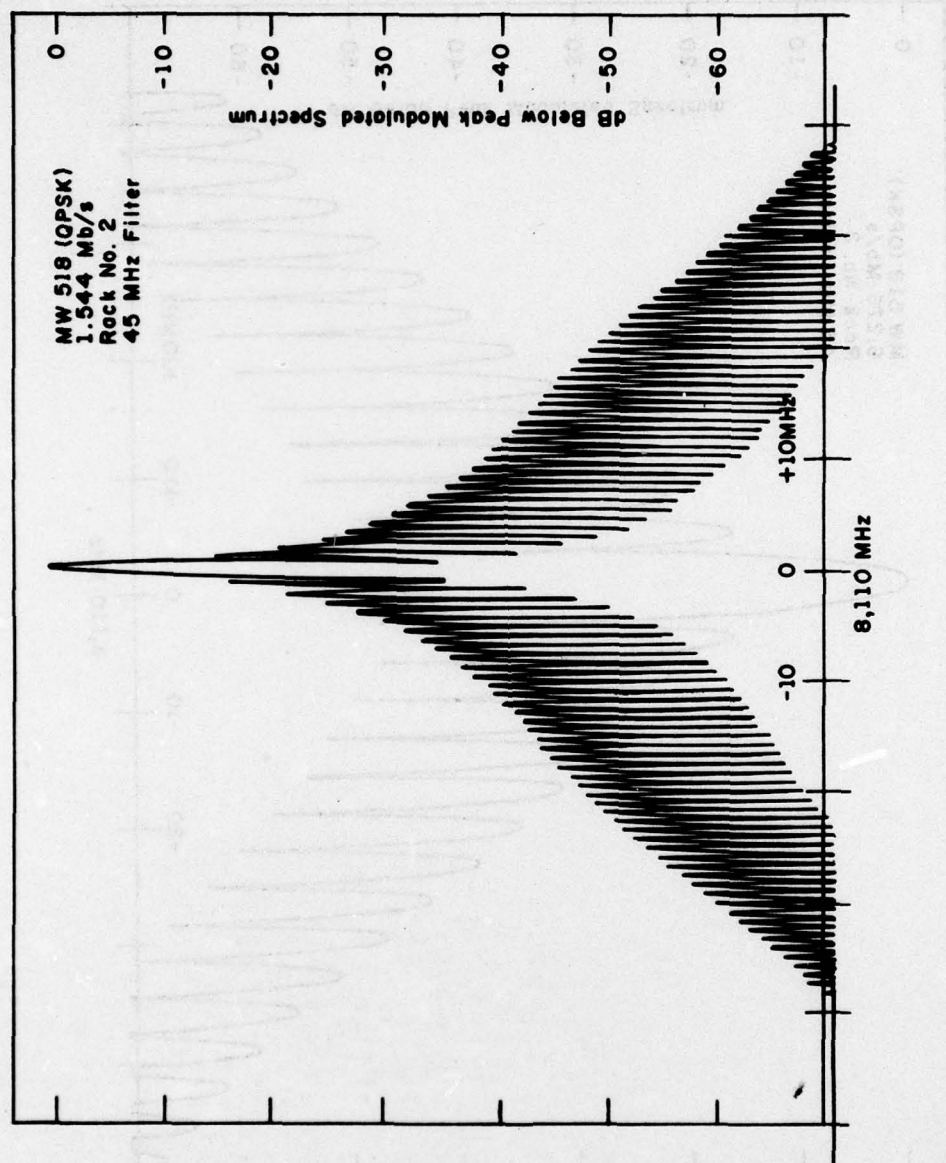


Figure 31 Power Spectral Density ($R = 1.5 \text{ Mb/s}$, $B = 45 \text{ MHz}$)

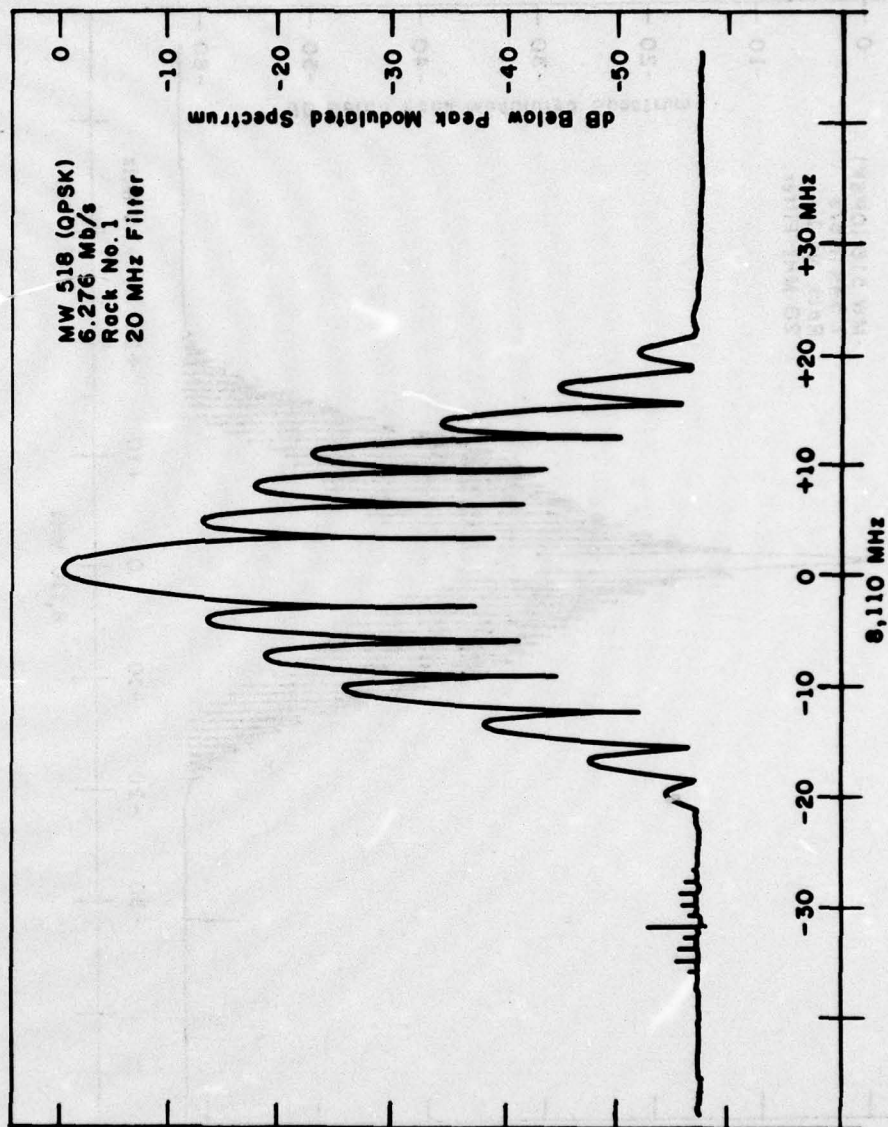


Figure 32 Power Spectral Density ($R = 6.3 \text{ Mb/s}$, $B = 20 \text{ MHz}$)

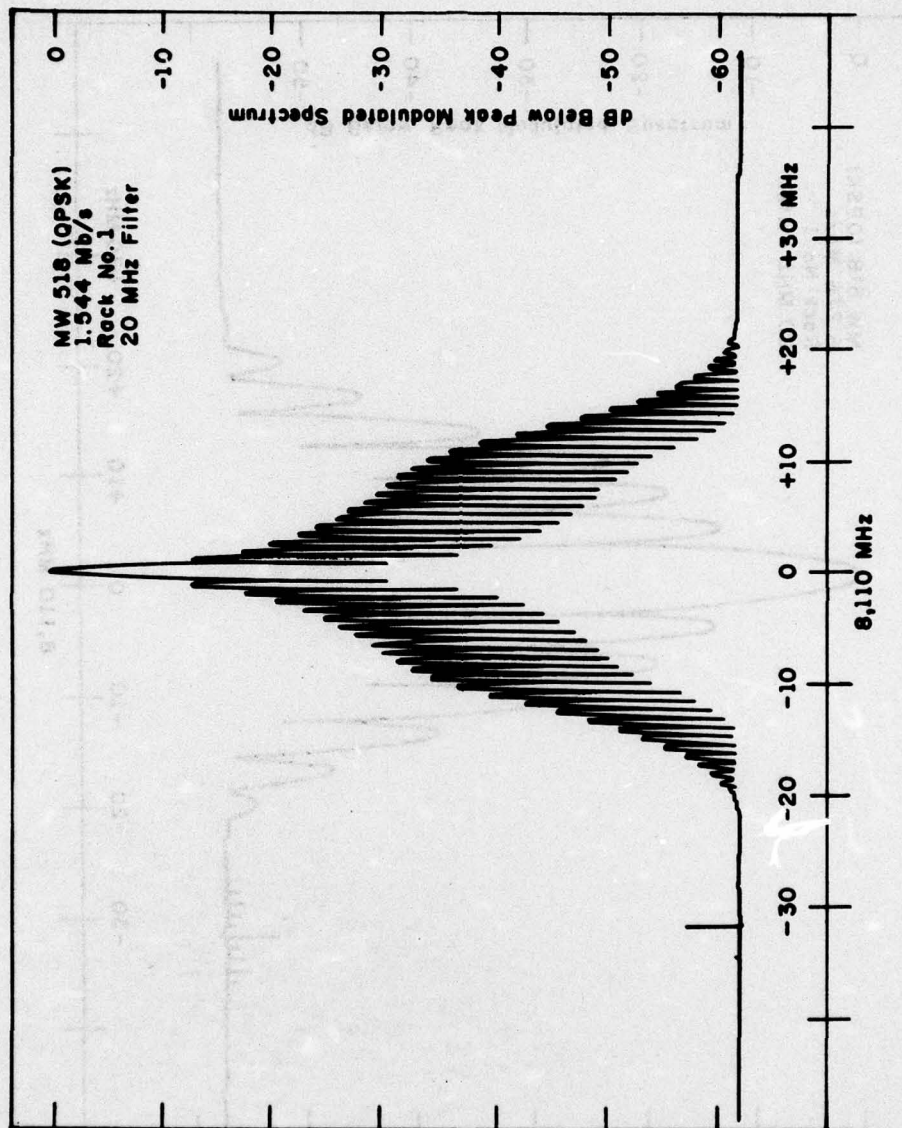


Figure 33 Power Spectral Density ($R = 1.5 \text{ Mb/s}$, $B = 20 \text{ MHz}$)

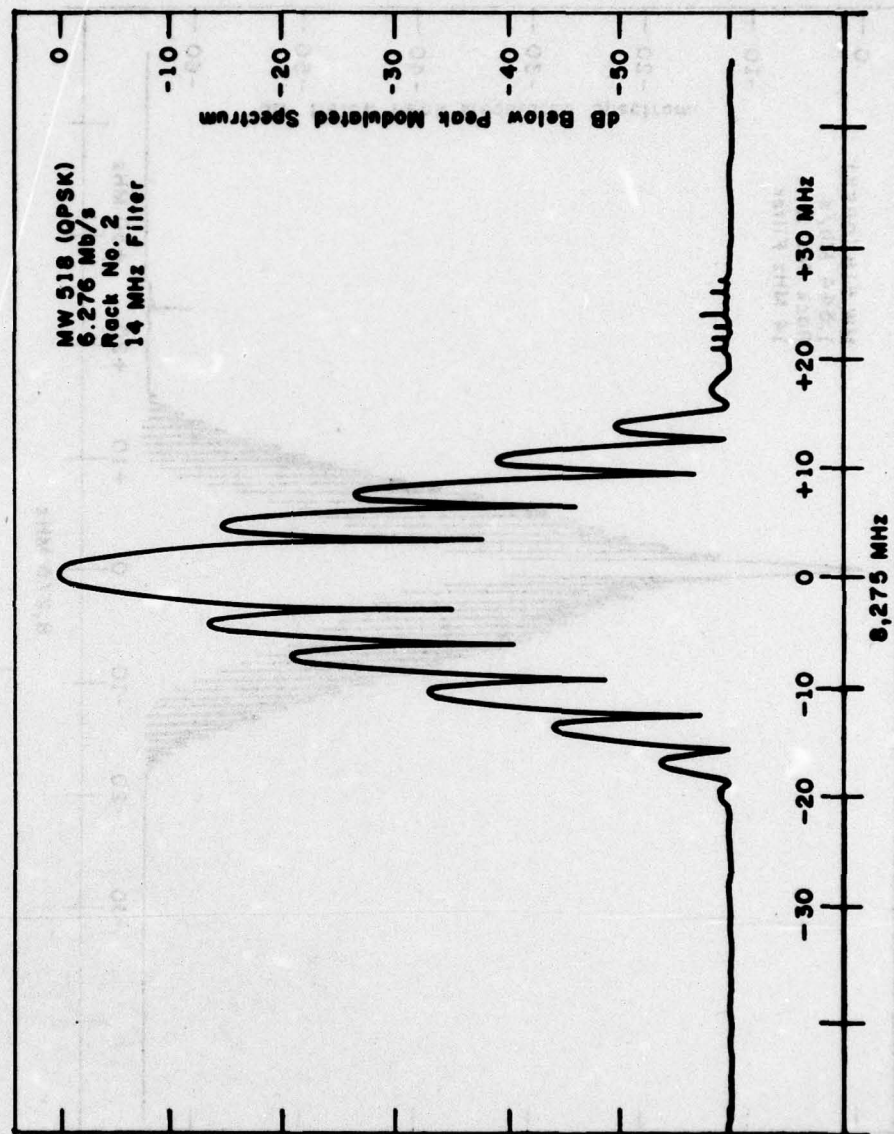


Figure 34 Power Spectral Density ($R = 6.3 \text{ Mb/s}$, $B = 14 \text{ MHz}$)

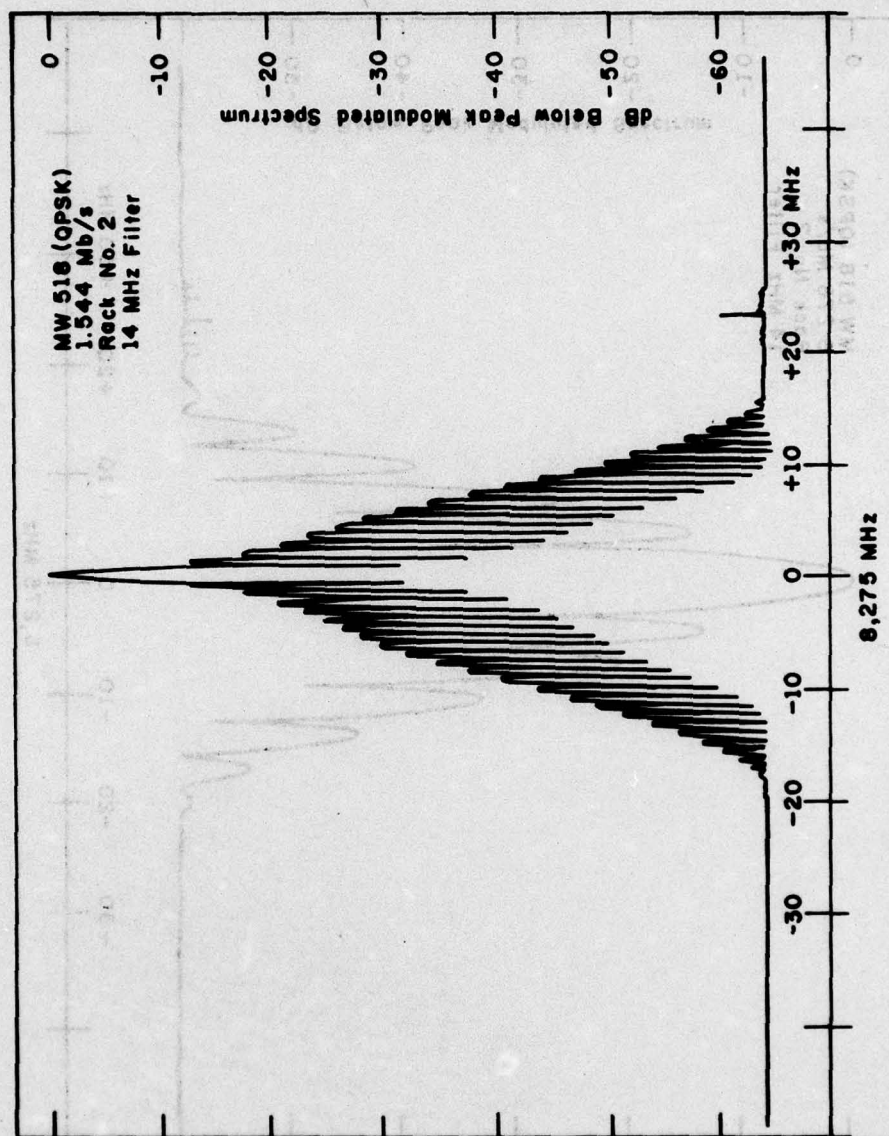


Figure 35 Power Spectral Density ($R = 1.5 \text{ Mb/s}$, $B = 14 \text{ MHz}$)

APPENDIX 2

FCC Docket Number 19311 was formally released on 27 September 1974 to be effective 1 November 1974. Pertinent points of this docket with respect to this report are the determination of necessary bandwidth and the emission limitations restriction. The determination of the necessary bandwidth of digital modulation using PSK (F9Y) is given by the formula $B_n = \frac{2RK}{\log_2(S)}$

Where: B_n = necessary bandwidth in MHz

R = bit rate in bits-per-second

K = 1

S = number of signaling states

Substituting the values for 12.6 Mb/s data into a QPSK transmitter yields:

$$B_n = \frac{2 (12.6 \times 10^6 (1))}{\log_2(4)}$$

$$B_n = \frac{25.2 \times 10^6}{2} = 12.6 \text{ MHz}$$

This means that for a system employing QPSK modulation, the necessary bandwidth in hertz is numerically equal to the bit rate in bits-per-second.

For systems operating below 15 GHz, the radiated emissions must be contained within a "mask" comprised of several segments. Measurements to apply these segments are required to be made in 4 kHz increments. The attenuation required below the mean power output is given by the formula:

$$A = 35 + 0.8 (P-50) + 10 \log_{10}(B)$$

Where: A = attenuation (in decibels) below the mean output power level

P = percent removed from the carrier frequency

B = authorized bandwidth in MHz

This must be tempered by two additional limitations; first the attenuation greater than 50 percent removed must be a minimum of 50 dB, and secondly, that attenuation greater than 80 dB is not required.

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